Digitalization of reporting and deviation control in the construction industry

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Preface

During the writing of this thesis, we have had the pleasure of meeting many enthusiastic and inspiring people, who have shared with us their time and knowledge. While we cannot mention everyone, we want to give a few a little extra attention.

Paul Svennevig, you have helped us calm down the nerves at various times, and we have shared many laughs together. We could not wish for a better supervisor and will look fondly back at the moments we shared together.

Trond Stupstad, your enthusiasm for technology is contagious, and we appreciate you for believing in us.

Smart Inspection gave us their time, lent us their equipment and enabled us to get the point cloud for the bridge. Parts of this thesis would look a lot different if you didn't help us.

Thank you to Kruse Smith and their employees that we met during the project, for taking time out of your busy schedule to answer our questions and sharing your knowledge.

Summary

This project aims to enlighten and evaluate the potential for utilization of 3D scanning for documentation and model updating, and the possibilities the horizontal construction industry has to implement model-based reporting methods. The theory in which this thesis is based on is primarily literature studies about research techniques, Building Information Modeling, enterprise form, and software.

The methods used in this project involved scanning of a bridge, processing the resulting point cloud and documentation of deviation. There were also conducted interviews and compared model-based reporting software to today's reporting methods for evaluation of the potential for improvement.

The use of 3D-scanning for model-based documentation is achievable but requires expensive, specialized equipment and software, and operators that have the necessary competence to exploit the potential.

Projects in the horizontal construction industry can accomplish model-based reporting by allocating more resources into creating models with sufficient detail level and their utilization. However, this requires the modern business model to accommodate digital development.

This thesis is a bachelor degree project, conducted by students at the University of Agder.

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1. Introduction

Alongside population growth and urban development in today's society comes an increased demand for transportation. Railway and road construction companies need to comply with this demand, while also being cost-effective and reduce the environmental impact. Road construction requires planning on a detailed level, as every incline, turn, cutting and filling as well as bridges and tunnels need to be calculated to make the roads safe. Because road and railroad constructions are large, expensive projects and are usually paid for by the public through taxes, there is a pressure on the industry to build roads and railroads as cheap as possible.

Digitalization has affected most of our society, resulting in higher productivity and efficiency. When it comes to the construction industry, however, the digital progress has not come as far as, for example, the component industry but is expected to develop fast in the following years. Building Information Modelling (BIM) is believed to be an integral part of the digitalization of the construction industry. BIM is expected to affect the future tender for most construction companies, and as such, many companies feel the necessity to learn BIM if they are to stay competitive.

This project is conducted in cooperation with *Nye Veier*, *AF Gruppen, Kruse Smith*, and *Smart Inspection*, and is also part of the MEERC (More Efficient and Environmental friendly Road Construction) research project, which is a combined effort between academia and the construction industry.

This report is a bachelor thesis for construction engineering and was chosen because through the course of our education we have caught an interest in the possibilities BIM provides. Therefore, we wanted to write this thesis to get the chance to be a part of the BIM development and increase our knowledge of BIM, both as a method and a technology.

An important question to answer is: how can BIM help the construction industry utilize resources more efficiently?

2. Societal perspective

Increasing efficiency in the construction industry is of high importance for society since the construction industry stands for 16% of the Gross Domestic Product (GDP) in Norway, and 40 % of the world's energy use and CO_2-equivalents [1, 2]. While these numbers may not be the most accurate, it gives indications for the size of the construction industry. As such, anything that affects the construction industry has the potential for significant change in the society, for better or worse. Since BIM is a technology and methodology that affects all parts of the construction process, from planning to Facility Management (FM), it has the potential to reduce CO_2 emission and cost significantly, and improve Health, Safety, and Environment(HSE) [3, pp. 16-21].

A way BIM can potentially help to reduce the environmental impact of the construction industry is by reducing waste. In this setting, waste is anything that is not optimal within the given parameters. Waste can be, for example, material waste from poor optimization of the design, material waste from redoing parts of a construction because of faults in the construction phase, energy waste in the form of unnecessarily high energy requirements that a better design could have improved on, and so forth. Because everything requires energy, and energy production has a CO_2 emission, reducing waste also reduces the environmental impact of the construction industry.

BIM could potentially also reduce the environmental impact of the construction industry by enabling better optimization of constructions. If there exists a complete digital model that has all information on a construction, one could, in theory, optimize every aspect of the construction, providing the best overall solution within the given parameters.

However, the future of digitalization could potentially reduce the need for workers, which again may lead to fewer jobs. Accordingly, included in the increased digitalization of the construction industry, which BIM is a tool for achieving, is the need for an ethical discussion.

3. Theory

The construction industry can be divided into two parts, the horizontal and vertical. The horizontal construction industry will for this thesis be defined as the construction of roads and the work needed to build roads. The main point for horizontal construction is that it typically has much foundation work. Vertical construction, on the other hand, is the construction of buildings. Construction building differs from horizontal construction in that the foundation is typically only done for the first floor, and adding floors does not add significantly to the foundation as the next floor uses the previous floor as a foundation.

3.1 Research theory

The following research theory and terms are mainly based on the book written by Dag Ingvar Jacobsen who works at the University of Agder [4]. Research terminology and methodology has also been guided both by student peer reviews and professor and engineer supervision.

Research projects vary in form and extent, and this thesis has used the terms and definitions as described in the sub-headings from 3.1.1 to 3.1.9.

Research is mainly split into two categories, qualitative and quantitative. Generating knowledge through statistically analyzing data, often gathered in surveys or observations, would categorize as quantitative. Measurement of knowledge and experience, and taking opinions into account, would describe qualitative research. Both research categories can be used in the two designs of research. Inductive research design would imply that the data would be analyzed in the purpose of establishing a new theory, while a deductive design works opposite; testing an existing theory by data collection [4], [5]. In general, the data collection phase of research can be deemed sufficient when there seems to be no additional significant information, and the data collected coincides with the previously collected data; The study has reached data saturation [4].

3.1.1 Research model

In projects where research is but a preliminary phase, and time and resources are limited, it could be beneficial to conduct intensive research. These can, for example, focus the limited resources on fewer objects but go more in-depth into. Thus a research project can achieve depth despite scarce resources [4]. Intensive research projects with few research objects; small N research methods; can compensate with prioritizing informants who provide the most information. This could be an example of prioritizing information and thus focus on informants with the most knowledge or experience, counteracting the limited resources. Research projects can also work by focusing on width and variation, beneficial when one seeks a cross-section representative for the entire population. Another option is extreme research, where one measures what is theoretically possible provided the resources are abundant [4].

3.1.2 Research objects

Inclusion criteria in a research project are specific properties the researcher deems necessary for a source to be valid or relevant. Exclusion criteria are the opposite; properties not wanted in the sources. Both qualitative and quantitative properties can qualify as inclusion or exclusion criteria and could be determined by the research hypothesis or the research question. On selection of interview objects, there are multiple types; Strategic selection of those deemed most relevant; Variation selection - gathering different experiences, opinions, perceptions, and perspectives; Type selection -

to measure the average; Comfort selection - when choosing those most accessible to contact; "Snowball-selection" – following up on contacts from other interviews and such; Random selection – choosing anyone available, as they are part of the selection population [4], [6].

3.1.3 Research case

Research projects can be affected by their definition of the case objects; a collective unit would mean all the involved parties in the given research project, whereas an absolute unit could be a particular unit such as a small team within the larger project. Time delimitation of the case objects would have a similar consequence on the results, as the definition of start and complete time would affect the data. When choosing units and deciding on whom to base the research on, one must consider several factors. A unit with relevant experience could answer subjectively from "within," acting as a respondent. While a unit with knowledge or information might answer objectively from "outside," being an informant. Anyhow, when deciding on the units, one should note their validity, which in turn should affect the analysis [4].

3.1.4 Research design

A cross-sectional study is a form of observational study where one can conduct qualitative research and still attribute some quantitative properties such as regression. Such a study model could be applied with a small N method and does not deny the option to change the research question during the project as new information changes the understanding of the subject. To ensure correct data gathering, however, it should be stressed that cross-sectional studies are prone to error in objectivity; The observer can perceive the data to seemingly vary too much when originating from the same population and in a short period, and try to correct it. Cross-sectional studies are beneficial if one wants an estimation on a broad theme, or for example the representation of an entire branch or industry [4].

3.1.5 Interview

Interviews can vary in formality and structure but revolves around the gathering of information from a unit. The unit could either be a group or a single object, with the latter having more of a person dependent nature. An interview requires a significant amount of preparation beforehand, which can culminate in an interview guide. The guide shall provide the questions, the broad themes, information necessary during the interview, and generally be an interview tool ensuring efficiency. The medium in the interview could affect the results by affecting the interviewee or perhaps leading to an error such as misunderstandings. The medium, be it telephone, video-conference, or in-person, should, therefore, be chosen based on who is being interviewed and what would provide the most valid data. A significant amount of time for proper analysis after the interview should be prioritized [4], [5].

The individual open interview can give the informant room to express themselves, and obtain information to the full extent of their experience and knowledge. By choosing an interviewee based on their insight on the given subject, giving them pointers to prepare for ahead of the interview, and setting them in their comfort zone both location- and medium wise, the data should be of quality and sufficient validity. An open interview demands a certain amount of preparation by the interviewer, as the interviewee should feel the interview to be like a pleasant conversation; which takes planning, preliminary research to improvise on the subject matter, an interview guide fit for improvisation, and general objectivity [4]. As a rule of thumb, however, people, as interested as interviewees might be,

are only invested in a conversation for 30-45 minutes. As such, the open interview should not be longer than one hour. Interviews benefit from a rapport between the parties, and an active interviewer can bring out the better in an interviewee. Instead of writing minutes by hand, one can consider taping the interview. This requires consent, and also the consideration of how the interviewee will answer differently with the knowledge that everything is being recorded [4].

Informal interviews have no prepared questions but instead subject themes and pointers. Although in-person informal interviews are regular and being more like a conversation, they could also be in the form of personal communication by e-mail or over the telephone. Informal interviews include a variation of mediums, and vary in structure and are more suited for qualitative studies [4], [6].

3.1.6   Source study

Source studies are primarily literature studies but do also include other sources like internet-based journals, reports or earlier research. Literature studies can compensate an interview of an unavailable informant or a prominent figure while maintaining its validity. Source analysis is well-suited for estimating today's situation, as in a cross-sectional study. It does, however, require precise inclusion criteria and objectivity in cross-referencing. One should seek primary sources and first-hand data as, for example, a research article [4].

3.1.7   Source Analysis

On risks when analyzing data, groups can develop a feeling of invulnerability, meaning that the group could become defensive towards change, or subjectively defend their point of view. This phenomenon can both be attributed to the researcher who defends their presumptions, and the informant who answers subjectively. An example would be that the traditional method of a given subject is glorified, while the new method is viewed as unnecessary [4]. The analyzing of the data should also consider its source and to whom the research was intended. Government or private sources and their possible subsequent subjectivity must be considered. Sources from institutional research can have different effects on the methodology than if it were conducted by an individual. The source level of significance is the term for separating between peer-reviewed articles written in science journals, and articles in a magazine [4]. On the source assessment, there are multiple reasons as to why sources could be misrepresentative of today's situation; outdated data, inadequately analyzed data and therefore wrongly concluded, biased personnel, human errors on either side in data procurement, or perhaps cherry-picked results; picking results that align with the presumptions.

3.1.8   Survey

Surveys are typically part of a quantitative study, applying statistics to induce the data of a limited population into a general population. The distribution and response rate would substantially affect the validity of the data. One can, however, conduct a qualitative study with the aid of a survey which would require different questions. A survey scheme can be distributed further and to more respondents, than one could interview, and fits well with a cross-sectional study. A survey scheme should distance the respondent from the surveyor, making it easier to answer objectively. Also, as one can respond to the survey distributed by e-mail at any time and place, a respondent could be more at ease and not affected by their surroundings during the survey. The development and phrasing of the questions can, however, impact the respondent's understanding of the question, and thus affect the data. The use of multiple-choice schemes could help the respondent understand and correctly answer the question, as well as lowering the threshold of completing the survey. In the

analysis phase, one must consider what the respondent's dispositions towards the subject are and if opinions can be inducted into the general. For a reasonable, valid analysis of the survey data, one should avoid too many variables in the survey scheme, or else it could be challenging to find the correlations [4].

3.1.9 Experiment

Experiments in a research project could serve multiple purposes. The observations or tests are relative to the research unit, meaning observations on a construction project would differ from a test of a software solution. An observational experiment could provide the research with some quantitative data of the software functions, which can be further evaluated. The user testing of a given software could be a form of qualitative evaluation where one seeks to gain knowledge, but also experience, to correctly assess the functions [4].

3.2 BIM

"[…] we define BIM as a modeling technology and associated set of processes to produce, communicate, and analyze building models." [3, p. 13]

BIM can mean either *Building Information Model* or *Building Information Modeling*. In this report BIM will be associated with *Building Information Modeling*, and as such BIM-model refers to a model that is built on the principles of BIM.

There are several misconceptions as to what is BIM, and people usually do not have a complete understanding of the term. Perhaps the most common one is the misconception that a 3D model alone is BIM. A 3D BIM model, however, does not just handle the building geometry but does also, in fact, associate the different model elements with attributes. This is where the "I" (information) in "BIM" comes into play. Without it, the model can only be used for visualization and not complicated building analyses that consider the different building materials, spaces, loads and other aspects. The model needs to utilize parametric intelligence. [3, p. 19]

A BIM model is made up of elements. Some software names elements for objects, while others differentiate between elements as anything in the model and objects as being parametric elements. For this report, there will only be referred to elements, as the minor difference is not meaningful in this case. An example of an element can be a wall, a door, a linked point cloud, or a cooperation model. An element can consist of other smaller elements, giving the designer flexibility and the ability to easier reuse and repurpose elements [7].

3.2.1 Dimensions of BIM

A 3D model contains three dimensions, x, y and z in a coordinate system along with element attributes. However, there can be more dimensions than three in an integrated BIM model. This depends on what kind of information and input the model receives. The fourth dimension (4D) is sequencing data, which means that information about progress is integrated into the model. These models will sometimes have the ability to visualize when, according to the construction progress plan, the different parts of the construction will be built. High-quality reporting on a project can assist in keeping the progress plan updated and accurate, enhancing the 4D aspect. The fifth dimension (5D) is cost information. In this dimension, the software will have integrated information about the cost of different resources in a project. 5D is an appealing tool for an owner when it comes to estimating and documenting the cost of a building. The sixth dimension (6D) is the lifecycle of a

project and includes the facility management (FM) phase of a project. This dimension may include information about manufacturers, installment dates as well as maintenance requirements. In short, 6D BIM provides as-built information for use through the entire construction lifecycle. [8, 9]

3.2.2 Benefits of BIM

Preconstruction benefits of BIM

Regarding benefits that accompany the implementation of BIM, there are four main topics. They are based on the different parts of the construction process, from the cradle to the grave.

During the preconstruction phase, it is in the owner's interest to be sure that the given building can meet specific financial requirements. Considerable savings can be made if a macro building model is made with a connection to a cost database, allowing the owner to expect with relative certainty that their goal may be achieved.

It is also desirable to determine a building's functional quality. This can be done by making a schematic model before a more detailed model is made. The general quality of the building can be evaluated by analyzing the different design alternatives beforehand, using a digital tool for such analysis.

Using Integrated Project Delivery (IPD) to improve collaboration, BIM can be used to create a better understanding of the requirements and cost estimates for the project.[3]

Design benefits

The ability to visualize the building design at any stage of the process can prove itself valuable. If not generated from several 2D views, but rather a direct 3D model, the design will be dimensionally consistent from every view. 2D drawings, however, can be extracted from the 3D BIM model at any time. In turn, this dramatically reduces the time and errors associated with construction drawings.

Rather than waiting for a design to be nearly completed before applying value engineering, BIM technology can process simultaneous design processes at once. This causes the design time to be shortened as well as securing fewer design mistakes, which in turn makes for a cost-effective design process. In addition, BIM provides quantity take-off for space and materials for a better estimate on costs. [3]

Construction and fabrication benefits

BIM fabrication tools can be used to show the building elements that are to be fabricated and constructed. A design BIM model combined with such a tool can provide an automated fabrication process because the components are predefined in the 3D model. An automated fabrication process such as this is being used for steel fabrication today.

In case any design changes are to be made, the update can be done quickly in the BIM model instead of the traditional paper sheets. This saves time because by using a BIM system the suggested modifications can be visualized, estimated and shared. Also, clash detection can be used to cross-check updates.

The combination of a 3D model with elements and a construction plan makes a 4D BIM. This makes it possible to visualize the construction at any time of the project as elements are linked to a specific time specified in the construction plan. Possibly, this can reveal problems that may occur in the

future as well as room for improvement. It can anyhow be beneficial to include the 4D perspective in the BIM. [3]

Post construction benefits

Information about materials and installations can be linked to the 3D BIM during the construction phase, making this information available for the owner after the takeover to be used during the facility management phase. A database with all the information about the building's systems is helpful for the owner when managing the facilities. [3]

[3]

3.2.3   The levels of BIM and BIM maturity

There are three levels of maturity levels for BIM, excluding level 0. Maturity level describes both the model itself and the work method for the design team. In other words, it describes BIM as a method and a technology. It is important to recognize that maturity level itself is just a small part of the description of BIM. Following are short descriptions of the different levels.

Level 0: BIM level 0 is not really to be considered BIM at all, as it relates to 2D Computer Aided Design (CAD) for use for design and product information.

Level 1: Level 1 represents the first step towards BIM. At this level of BIM, all the designers work in isolation, and not in any conversation with one another. This level of BIM is therefore known as *lonely* BIM. Each of the designers utilizes CAD in a 2D or 3D format alongside an approved software, granting a shared data environment.

Level 2: Managed 3D format in a separate BIM discipline software tool is BIM level 2. At this level, data is attached to the model. Level 2 BIM may introduce the first steps to utilizing sequencing data and cost information, which goes by the name of 4D and 5D respectively.

Level 3: BIM level 3 is an entirely integrated project model. To make this possible, software cooperation issues will have to be overcome, as this level of BIM will utilize several dimensions such as 4D and 5D (as mentioned in BIM level 2) as well as 6D project life-cycle and perhaps even more. This combination of dimensions is sometimes referred to as just "XD."[10]

3.2.4   Level of Detail (LOD)

A BIM-model is made of multiple elements that can vary in how much information they contain. To ensure everyone has the same definition of how detailed an element is, *BIM Forum* defines what information is required if an element is to be on a specific detail level [11]. This is important because different phases of a project require different detail levels. The different levels of detail (LOD) are called LOD 100, 200, 300, 350, 400 and 500. All prior requirements need to be fulfilled if an element is to be of a specific LOD. For example, an element cannot be LOD 400 if it does not meet all the requirement of a LOD 350 element.[12-14]

LOD 100 – conceptual design: A LOD 100 element contains barebone information and can be represented with a symbol, or with elementary geometry in the model.

LOD 200 – Generic placeholders: A LOD 200 element is a generic placeholder and contain approximate quantities, size, location, shape, and orientation. This is also where the earliest non-graphical information can be stored.

LOD 300 – Detailed Design: At this level elements need accurate information whereas before, approximations where enough. This is also the first level where the model is detailed enough to be used in production, although it does not contain all the details.

LOD 350 – Construction Documentation: LOD 350 adds how an element interfaces with other construction elements.

LOD 400 – Fabrication & Assembly: At this level, the element is a complete representation of what it would be in real life, including all necessary documentation.

LOD 500 – As built: A LOD 500 element is virtually identical to a LOD 400, except as where a LOD 400 element shows what the designers intend to be built, a LOD 500 show what has been built. As such, a LOD 500 serves as an update to the element, from as designed to as built. This is very important if the BIM-model is to be used for Facility Management (FM).

Figure 3-1 shows the graphical progression of an H-beam as it goes from a LOD 100 element to a LOD 400 element, demonstrating the effect LOD has on an element.
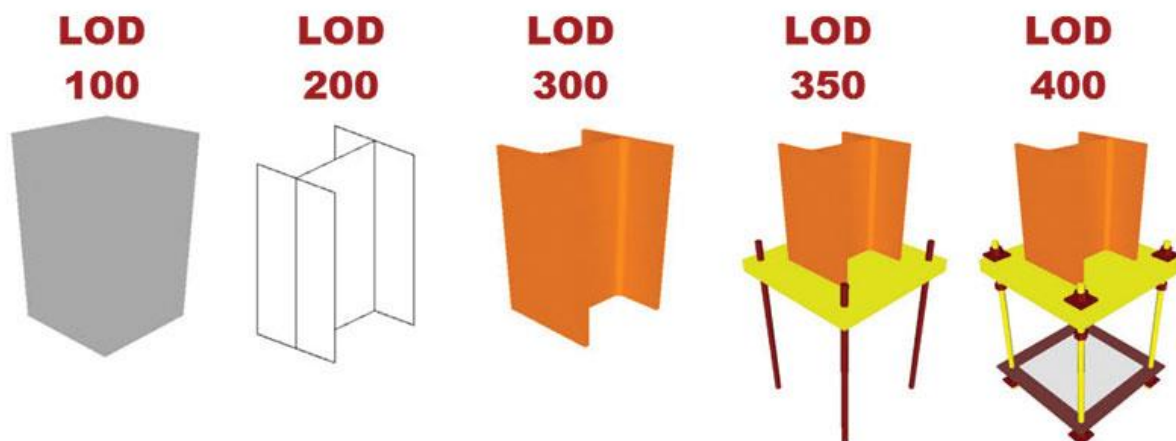
Figure 3–1 The progress of an H-beam as it goes from LOD 100 to LOD 400[12].

It can be beneficial to specify a minimum LOD for specific phases in the project. In the earliest stages of design, a LOD 200 could be enough, but a minimum of LOD 300 could be enough for production drawings.

3.2.5   OpenBIM

BuildingSMART's mission is:

> *"Contribute to the sustainable built environment through SMARTER information*
> *sharing and communication using open international standards in the building*
> *and construction sector, private and public."* [15].

In cooperation with the International Standardization Organization ISO, *BuildingSMART* develops open standards for BIM. Essential motives for achieving open standards and workflows include; participation regardless of software tools, a common language for processes, lasting data in use throughout the life cycle, non-monopolization of the software market, and accurate data delivery in BIM [16]. The standards are mainly concerning terms, processes, and data, visualized in the figure 3-2.
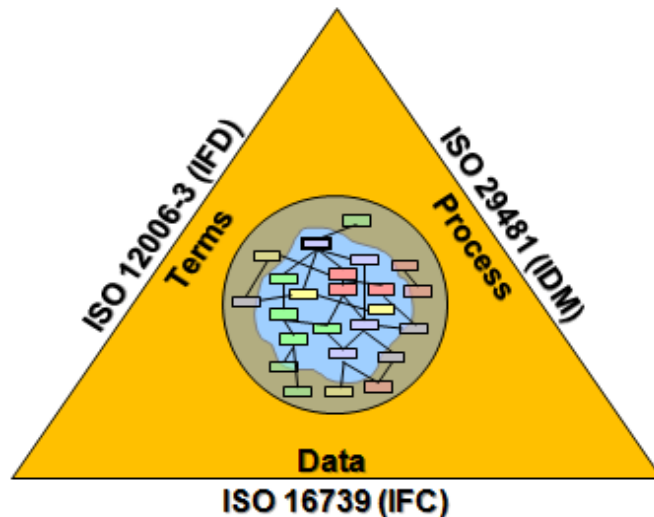
Figure 3–2 The standard data model, process, and terms in openBIM [15].

This project focuses on the collaboration using Industry Foundation Classes (IFC) and the addition BIM Collaboration Format (BCF), and does not take the Data Dictionary Standard – International Framework for Dictionaries (IFD) and the Process Definition Standard – Information Delivery Manual (IDM) into account [16].

IFC is meant to enable interoperability and collaboration through an open specification BIM-data model in the construction industry. By exporting to, and importing, via the open IFC-format, one should be able to work on a model using different software. Thus, different tasks in the model, such as collision control and task scheduling can be done in the software which is best suited [15].

BCF aims to include the information that IFC cannot process. The BCF format includes the transferring of text, pictures, viewpoints in the model, snippets from BIM, position, and angle, assignee, logs of sending and receiving, status, type, and references to the IFC model. This information aids in the communication and makes collaboration based on IFC models possible. In 2014 bcfXML v2 was adopted by *BuildingSMART* from *Solibri* and *Tekla*. This version made it possible to append BIM elements in the BCF report, like for example a column or a zone such as a room. Working with BCF is a form of communication that centers around the BIM-model without being dependent on the model's limits in interoperability, the information can be sent either through plug-ins in the BIM software itself or by e-mail [17], [18], [19].

The amount of BCF communication in larger projects makes a system of an organization necessary. In 2014 a web service called RESTfulAPI v1 was developed. Instead of sending each BCF report individually, RESTful API v1 functions as a BCF server, which synchronizes the BCF tasks [17]. Some authentication is to be in place to ensure that each party only get access to the data they need, both a means to lessen the amount of information, but also as a safety measure [17]. A combination of the project BIM server, with the BCF server, has been suggested and can be visualized as in the figure 3-3 [20]. It is important to note that others suggest a decentralized server structure, as the content itself does not need to be in one place, and instead develop the linking of information [21].
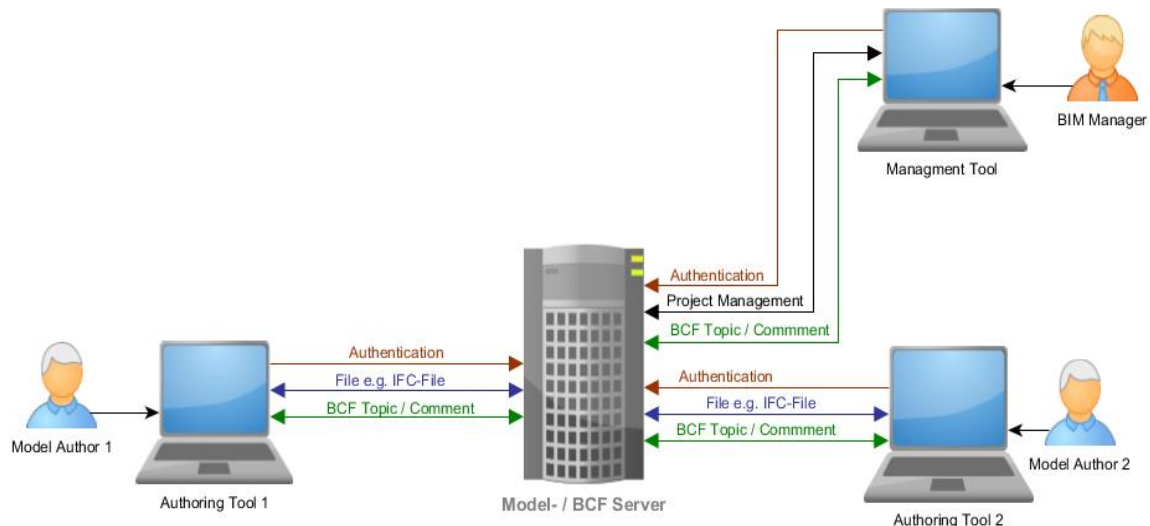
Figure 3–3 Visualization of a Combined Project BIM and BCF server, making it possible for all parties involved to collaborate [22].

3.2.6   Object-based parametric modeling

One of the most fundamental aspects of BIM is object-based parametric modeling. Object-based means that one designs something on a per object basis or per element basis, enriching the element with non-geometrical information. This is different from traditional 2D CAD modeling, as 2D CAD is on a per line basis. The parametric part is some of the intelligence of BIM, as elements understand its relation to other elements. For example, if the roof height is changed, the connected walls move relative to the roof, if this is wanted. This makes design changes easier as a change is propagated to all views. An added benefit of this is the possibility of reducing errors that initiates from forgetting to do a change in all views [3].

3.2.7   Expected challenges with Collaboration and Teaming

A model in a project needs to be adequate for the construction process, with element information, quantity takeoff, estimation, and coordination. If the architect of a building were to design a building by using paper drawings, then the contractor would have to create the model for it to be sufficient. Likewise, if the architect, however, designs a building using BIM the contractor might have to add information to obtain the desired level of detail sufficient for the construction process. This may even result in the need for a new model for construction use. These are examples of BIM-work that need to be accounted for in the contract so that the work can be invoiced to the contracting client.

There are many different modeling tools on the market. If a project team were to have different tools in use within the group, it might cause issues with file format alongside the model information. By using the IFC format, data exchange issues can be reduced. However, not all modeling software cooperates on the same level with IFC, risking some information to be lost in the process of sharing. A contract could, therefore, include software

If BIM as technology and method is to be fully implemented in the industry, it requires a remake of the traditional business model for a firm. This means that contracts have to be written in a way that benefits the use of BIM in the project, which in turn requires extensive knowledge from the legal team to cover the different aspects and issues that comes along with this implementation.

Additionally, there is a lot of training and software required for a company to be able to stay updated. A helpful measure could be to hire a consultant to help with monitoring such a process. [3]

3.2.8 From point cloud to model

The process from a point cloud to BIM is currently a very manual process. There exist no satisfactory automated solution, and an operator will have to intervene in the process at different points in time. As of 2016, it is estimated that 85% of the labor is done after the point cloud data have been collected [23]. It needs to be stitched together, cleaned up, checked for errors and be optimized. Then a modeling expert needs to create the BIM-model from the point cloud, using specialized tools. This is currently a mostly manual process, but innovation in software capabilities could result in a higher degree of automation in the future [24].

3.3 Contract and business model

3.3.1 NS 8405

Chapter 3.3.1 is based on the book "NS 8405 with commentaries" [25]. Norwegian Standard (NS) offers a variety of standards, contracts being among them. NS 8405 is often used between the general contractor and the contracting client in construction projects where the scope requires formalized procedures of notifying, and broad requirements to coordinate all involved parties. The contract standard prerequisite that most of the projecting is provided by the contracting client, and shall not be used with end-customer [26]. NS 8405 is the primary contract standard because it was the base for the development of the other standards in the 84XX-series. Many of the rules are the same across the standards, and knowledge of the NS 8405 easily translates to the others [27].

3.3.2 NS 8415

The contract standard NS 8415 is aimed at the sub-contractor and their agreement with the main contractor. NS 8415 is approximately equal to NS 8405 except a few considerable differences [27], [28].

Significant differences are as follows:

(1) The rules regarding facility takeover, and thus for complaint deadline and more, the takeover is synchronized between all parties; contracting client, general contractor, and sub-contractor. This may lead to the situation of the sub-contractor finishing their work significantly earlier than the takeover itself, which leads to a longer period for errors to occur in the construction. This is addressed in 32.1 in NS 8415 and

(2) The discrepancy between NS 8405 and NS 8415 as described in 18.4 NS 8415 gives the general contractor the right to intervene (conduct parts of the work) if the sub-contractor is delayed.

(3) A significant difference is 32.2 in NS 8415, which gives the sub-contractor the right to notify their work as completed to the general contractor, and thus transferring the responsibility and risk, even though the takeover is at a later time [27], [28].

3.4 Software

3.4.1 User-friendliness

User-Friendly software is characterized by certain qualities. The software should have as few options as possible to choose from when wanting to complete an action, meaning every available option

should have a relevant reason for being available. This makes for a simpler navigation process. The software should also keep image and color choice consistent and logical. If the software is available for use on PC as well as smartphones and tablets, the user should see the similarities between the platforms. A good rule of thumb is that the software should not be in the way of completing a task, but rather an assisting tool. [29] [30]

3.4.2 Field management software

A field management software is designed for use during the construction phase of a project. They often share some functions with facility management software, but with different goals. The similarities lie in the task management functions. Since field management is about the construction phase, the software will often include the ability to report deviations, create tasks and delegate them. A field management software could increase the percent of issues reported by lowering the threshold. Also, obtain an accurate, automated and efficient information flow, keeping a user-friendly interface, and maintain records of all project reports.

Field management, in general, is control of a construction project regarding workmanship, physical properties, equipment, and material supplied by the contractor towards the design plans and specifications[31]. Reporting of Unwanted Incidents (RUI) is in this thesis also considered part of Field Management. Reporting of Unwanted Incidents (RUI) is a general category, where the incident could be either a deviation from the planned design specification or perhaps a situation where rules were not followed. An HSE (Health, Security, and Environment)-report would categorize as an RUI [32-34], [Appendix 2].

3.4.3 Facility management software

There are software solutions made to ease specific links in the process of planning, projecting, constructing and managing. Facility management (FM) software are mainly designed to be used in post-construction phase. This type of software is not to be confused with modeling software such as *Revit,* a commonly used program. Some FM software allows a BIM to be imported to display the model. Tasks may then be established directly into this model. For this process to be ideal, there is a need for the BIM model to be complete, updated and enriched with information during the phases leading up to, and during, the construction phase. Consequently, the FM phase has a sustainable foundation and applicable software [35].

3.4.4 Byggeweb Capture

Byggeweb Capture [36] is a software used for construction site monitoring, deviation control, pre-inspection, post-inspection, checklist and delivery of the finished construction. In addition to regular computer use, it is also accessible on smartphones and tablets. Tasks created are connected to 2D-drawings with self-taken pictures attached. These reports can be exported to either XLSX or XML file formats, which are spreadsheets. *Kruse Smith* uses *Capture* on more than fifty projects as of today (see Appendix 13).

[37]

3.4.5   Dalux Field

Dalux Field[38] is a field management software for managing tasks and reports in a project using a 3D BIM model. The software can import IFC[15], DWG[39] and PDF files, and export PDF, XLSX, and BCF [17] files. It is possible to create an organization within the program to organize the order of reporting and to decide which tasks are assigned to whom, which is convenient when doing checklists. This means that one can, for example, create an organization for wastewater engineering where all reports on wastewater will be received by someone in this organization. The process of generating a report on a deviation will be archived as a task which can be delegated further by the project organization. In other words, a construction worker will receive the notification in the form of a task, while a project manager will receive it as a report. It is not to be confused with two different files.

There is a 3D viewer embedded in *Dalux Field*. This viewer is also available for smartphones and tablets. Within this viewer there are two primary functions; any part of the modeled construction can be hidden to show elements that were covered and report generation of five different kinds. One can choose between test, register, quality assurance, deviation, and deficiency. Once a report has been created it is possible to select who the report will be sent to, as well as a picture, positioning in the model, and a description. When completed, the task will appear in a list. The person responsible will then have the opportunity to declare a task completed or suggest a follow-up. This process works in a hierarchical system that was built in the beginning, in the creation of the different enterprises [38] [40]. See appendix 22.

3.4.6   Autodesk Revit™

Autodesk Revit™ [41] (from here referred to as *Revit*) is a BIM modeling software and is owned by *Autodesk*. *Revit* was first released in April 2000 and initially developed by *Revit Technology Corporation*. *Autodesk* bought *Revit* in 2002 and is continuously developing its capabilities[42, 43].

Revit is a multidiscipline BIM-software with support for the 4D design of architectural, structural, mechanical, electrical and plumbing (MEP). *Revit* can read DWG files from *Autodesk AutoCAD* and import and read IFC models[41].

3.4.7   Autodesk ReCap™

Autodesk ReCap™ [44] (from here referred to as *ReCap*) is a software solution from *Autodesk* to view, combine and edit point cloud data [44].

3.4.8   Faro® Scene

Faro® Scene [45] (from here referred to as *Scene*) is a software for viewing, combining and editing point cloud data. It serves the same functions as *ReCap* but has more advanced features and subsequently also a higher skill ceiling [45].

3.4.9   PointSense for Revit®

PointSense [46] for *Revit* is a *Revit* plugin made by *Faro* that provides *Revit* with extended features and tools to work with a point cloud inside *Revit*.

PointSense enables tools to automate the process of creating an accurate BIM model from a point cloud. It can create walls, levels, doors, windows, roofs and many other features. *PointSense* has tools for automatic detection of wall placement, although it requires some input from the user. Moreover, it also has tools that enable faster creation of accurate *Revit* families, which help to reduce unnecessary work on repetitive features.

PointSense for *Revit* can also create topography from a point cloud [46].

3.4.10 Autodesk Navisworks™

Navisworks [47] is a software made to coordinate models from different disciplines and can import more than 60 different file formats with the *Navisworks* tool *Append*. This is useful when different professions are to collaborate their models, and there is the need for visualizing models with different file formats as one model regardless if it is for a complete visualization for the project model or to do clash controls between the different models in the project. Based on this, *Navisworks* creates a coordination model. *Navisworks* also allows for third-party software developers to develop software that builds upon the *Navisworks* platform to be able to do operations outside the tools embedded in *Navisworks* [47, 48].

3.4.11 Verity™

Verity[49] is a software made by *ClearEdge3D* for an automated deviation check between a projected model and scan data in the form of point clouds. It has smart detection of collision and missing elements and the ability to update the *Navisworks* model from as designed to as built. *Verity* works in close integration with *Navisworks*. *Verity* also has a native ability to generate reports of verification, making it suitable for documentation [50].

Verity can use every three-dimensional model that can be imported in *Navisworks*. For the point cloud, *Verity* can only manage a structured none unified *ReCap* project. It is recommended that both the model and point cloud has global coordinates specified to the real-world placement of the construction, for the test result to be credible [50-52].

The workflow of *Verity* starts by importing both the point cloud and the wanted models into *Navisworks*. When both the point cloud and the models are imported and positioned in *Navisworks*, then the elements and the point cloud must be added in *Verity*. Before starting the analysis, *Verity* gives the option to change display units and the tolerance value. The tolerance value is a user-defined value that *Verity* uses to test against the total translation of elements, to decide if an element passes or are out of tolerance [50].

When running an analysis, *Verity* automatically checks the elements and creates a copy to fit too the point cloud. The copied elements are addressed as the as-built position in *Verity* and are the points *Verity* uses for measurements the as-built element to the as-designed model. As shown in figure 3-4 as-designed elements are purple, and as-built elements are blue [50].
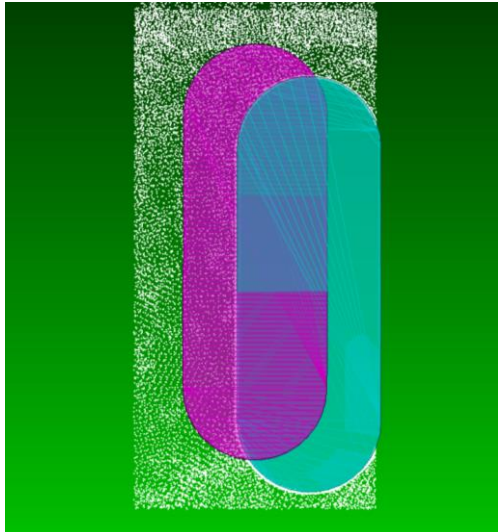
Figure 3–4 Visualization of elements in Verity displays the as-built element as blue, this is the copied element fitted to the point cloud. The as-designed element is displayed as purple.

When the analysis is finished *Verity* opens an HTML report for the installation status of the elements added to *Verity*, and then sorts them into eight different statuses. The installations statuses are explained in table 3-1 [50].

Pass	Item was installed within the specified tolerance (less than or equal to)
Out Of Tolerance	Item was installed outside the specified tolerance (greater than)
Uncertain	Point data was inconclusive or contradictory for this item
Occluded	Captured points obscured the geometry location, so we cannot tell what it is
Not Found	Points would have been captured if the geometry was there, so it is missing
Not Enough Data	There are insufficient points to analyze this item
No Data	There were no points in the space around the item
N/A	Not applicable because no as-built location was found

Table 3-1 Installation statuses cited from Verity User Guide [50].

The installation statuses can be changed in *Verity* by the user after the analysis is finished. If an installed element has a known placement and *Verity* cannot fit the element to the point cloud the user can modify this element and relocate the element. The result data within *Verity* for maximum translation and rotation will update automatically [50].

To understand the deviation between the as-built point cloud and as-designed model, *Verity* has a heat map tool that shows the distance from the as-built point cloud to the as-designed model as a colormap. The color scale moves from blue to red as shown in figure 3-5. Blue is where the deviation is at its maximum on the inside of the as-designed element. Green is where the deviation passes the user-defined tolerance. Red is where the deviation is at its maximum on the outside of the as-designed element [50].
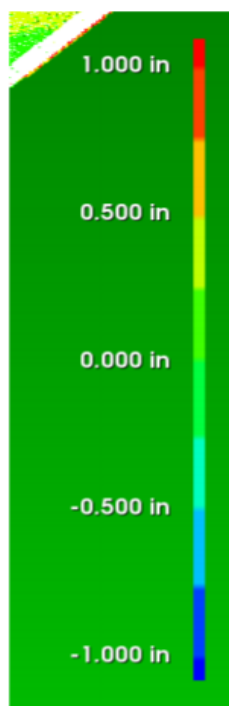
Figure 3–5 Heatmap scale from verity user guide [50]

Elements in the analysis can be marked reviewed with the approver's name. Elements can also be marked with an action required, and comments can be added to the element. After elements are reviewed in *Verity*, *Verity* can write a report for distribution. The analysis contains all the information within *Verity* [50].

Elements that do not pass the analysis can be automatically moved to the as-built position with the tool "move host item to as-built" in *Verity*. Automatically movement of elements to as-built changes only the position of elements in the *Navisworks* model. According to a salesman from *ClearEdge3D*, *Verity* may have the possibility to update elements automatically to the as-built position within *Revit* in a new software extension that connects *Verity* to *Revit* [50, 52].

The analyzed data can be imported to the *Navisworks* elements with the tool *export Verity properties to host*. This will colorize the elements in *Navisworks* according to the installation status of the element. Table 3-2 explains the color code connected to the installation status. The *Navisworks* model can then be used to update another model in a different software manually [50].

Pass	Green
Out of tolerance	Yellow
Uncertain	Salmon
Occluded	Purple
Not found	Red
Not enough data / No data	Teal

Table 3-2 Color codes for the installation status that Verity implements to the elements in Navisworks [50].

3.5 LiDAR scanning and point cloud

3D Laser scanners, *LiDAR* stands for light detection and ranging and are the technology used to read the surface of a structure. *LiDAR* calculates the distance and the angle from the scanner to the surface and sorts the information into a point in an x,y,z-coordinate system. 3D-laser scanners can measure more than 500.000 points per second. Each point is then assembled to create a 3D view of the surface. With a camera included in the process, a real photographic 3D view is achievable. There are different types of *LiDAR* equipment from aerial to groundworks. The aerial *LiDAR* equipment for planes is used to measure the topography of the terrain. Drones can handle both topography and scans for structures. *LiDAR* ground equipment is used for structures and small land surveys, also called terrestrial *LiDAR*. The *LiDAR* equipment for groundworks are either handheld or mounted on a tripod. The *LiDAR* equipment is capable of a 360-degree scan with longitude up to 70 to 350 meters. Data from the scans are then processed, registered and indexed into a systematic point cloud by using a processing software. The scan data that are generated into a point cloud is reliable and accurate enough to use as a reference when measuring and planning a project. With a GPS device mounted on the *LiDAR* equipment, it is possible to geo-reference the point cloud [53-55].

3.6 Certificate of conducted work

Contractors are required to provide certificates of conducted work with measurements and other documentation necessary for control[25]. The purpose is for the contracting client to calculate the invoiced sum correctly. The extent and content of the certificate of conducted work depend on the form of recompense stated in the contract. In fixed-priced contracts, one uses the measurement letters to document that the project progress is by scheduled progress. With contracts based on calculations of amounts with fixed unit prices, for example, concrete price per cubic meter, the measurement letters of actual volume worked or units used, must be added. On daywork contracts, one must add timesheets, invoices of material purchase, and other proof of expenses, which also applies to sub-contractors [25].

As a basis, the contractor determines which documentation to add. However, it is beneficial for the contractor to add more than necessary, rather than too little, as the contracting client can rightly deny the contractor recompense if the documentation is deemed insufficient. If the documentation provided by the contractor covers the terms given in the contract form, the contracting client cannot demand additional documents, if so; this must be specified initially. The provisions NS 4301.20 and NS 3430.24.2 determine the contractor's obligation to provide measurement documentation and procedure, and who is responsible for conducting the measurements [25].

The purpose of the measurement documents is to provide a basis for recompense, and progress payment calculation. The rules of measurements are specified in each contract, and would, for example, demand the use of leveling, either laser or optical, in the measurement mass balance. The obligation to conduct measurements lies with the contractor, but also the costs. The contracting client can choose to be present at the measurement to oversee and control but at their own expense [25, pp. 455].

From conversations with an assistant project manager from *Kruse Smith*, certificates of conducted work are done manually by one of the employees who manually takes measurements with the use of, for example, a measuring tape or a handheld laser measure to calculate the volume of a specific

element like the abutment or a column. The certificate of conducted work is used to prove that the volumes of the construction are correct and follows the requirements given in the contract [56].

3.7 Comparing point cloud to a model

Studies prove that using a point cloud against a model is a valid method for finding deviations[57]. One way of doing this is to create a heat map of the deviations, where a color range indicates how significant the deviation is, and it is even possible to differentiate what kind of error is found based on the pattern from the heat map. Figure 3-6 shows an example of a heat map, and how different patterns implies which errors are found.
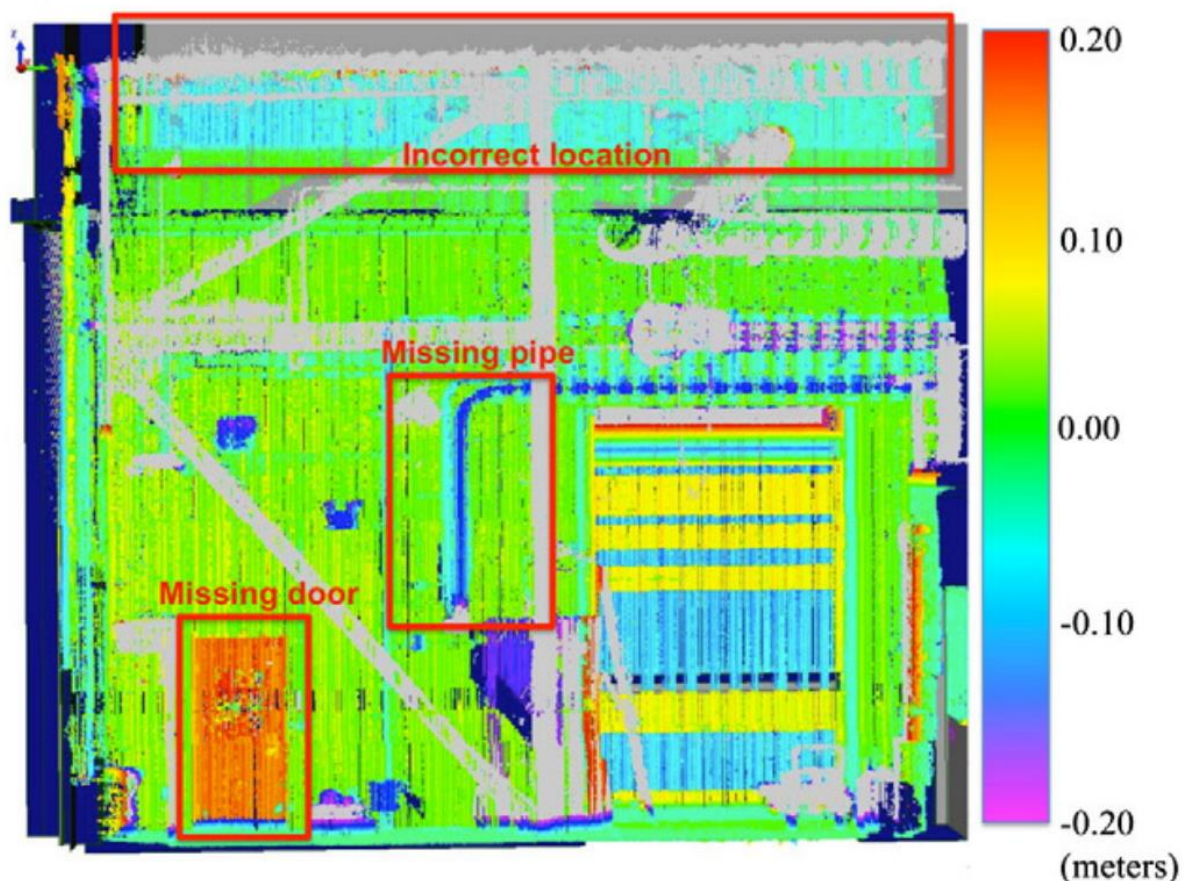
Figure 3–6 Heat map of deviations between a model and point cloud [57].

A study found that using point cloud against a model found 5.6 times more errors compared to a manual, physical check in the same case, using only 60% of the time [57]. These positive results are without using tools that automate the process, like *Verity* [49]. While the numbers seem very positive, it is important to note that this project had many rooms with many different objectives.

4. Research question

How achievable is the use of 3D-scanning for model-based documentation, and how can a project accomplish model-based reporting in the horizontal construction industry?

To answer the research question, the group will answer the following sub-questions:

- How can 3D-scanning be used to document whether the construction is built according to the BIM-model?
- How can the *Revit* model be updated from "as designed" to "as built" using a point cloud of the bridge?
- How can a procedure be composed for 4D model-based reporting of deviations found in the construction phase?

Because a BIM-model can consist of many different models from different software, this report will only look into how to update a *Revit* model from as designed to as built. This limitation is both because of time constraints, and that *Revit* is the software we have prior experience with. Also, only the placement and dimension of elements in the BIM model will be considered for 3D-scanning.

The model-based reporting will only investigate RUI deviations found in the construction phase, and not include anything on how to prevent deviations. Reporting of HSE deviation will only be briefly mentioned, as it is necessary to paint a bigger picture of software capability but will not be part of the research.

While cost is an essential subject for a contractor when judging where to invest, this will not be investigated or measured in this thesis. This excludes both the cost of implementing new systems and also the expected gain.

5. Case

The project case for this thesis is the new European route 18 highway from *Arendal* to *Tvedestrand,* that is of the larger E18 southeast projects, as seen in figure 5-1[58].

Figure 5–1 Overview of the E18 project. The dark red represents the new E18 between Arendal and Tvedestrand, and the black arrow is north [58].

The all new highway between *Arendal* and *Tvedestrand* will be 23 kilometers long with four lanes, have a speed limit of 110 km/h and a capacity of up to 20.000 cars per day. Included in the project is also 14 kilometers of side roads, and a total of 27 bridges, four tunnels, and several culverts. Figure 5-2 shows the planned route of the *Arendal-Tvedestrand* highway. However, these numbers could be incorrect as the project are subject to minor changes over time, as small optimizations could be found. The regulation plan for the project was concluded in 2014 by *Arendal* and *Tvedestrand* commune and accepted by *Nye Veier* and *AF Gruppen* in 2016. The road is expected to open in 2019[59].
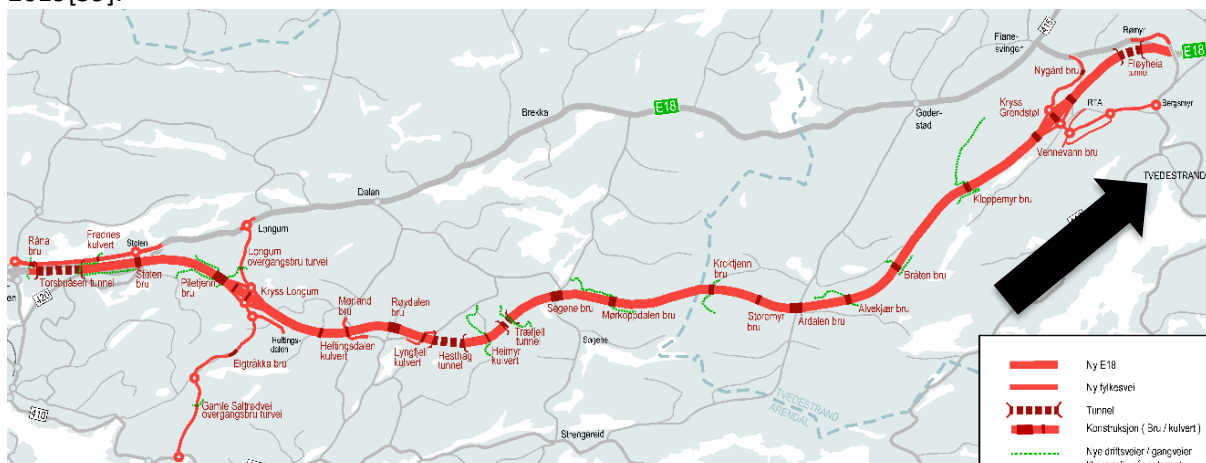
Figure 5–2 The planned highway, with Arendal is on the left side and Tvedestrand on the right. The black arrow shows the approximate north direction [59].

This thesis is supervised by the technical director in *Kruse Smith*, *Trond Stupstad*. *Kruse Smith* is involved in the E18 project as a sub-contractor under the general contractor *AF Gruppen*. During the contracting phase, *Kruse Smith* and *AF Gruppen* negotiated on the contract standard NS 8415, which means their contract may have some discrepancies with the contract standard template. *Kruse Smith* is among other things responsible for the bridges *Røydalen* and *Mørland*.

The bridge that will be used for point clouds is *Mørland* bridge. *Mørland* bridge goes over the highway, allowing a side road to pass over, and its placement is noted by a blue circle in figure 5-3. The bridge has two lanes, a span of 51 meters and a width of 7.5 meters. It is a straight bridge meaning no horizontal curvature but has a vertical curvature equal to a radius of 1100m, as seen in figure 5-4.
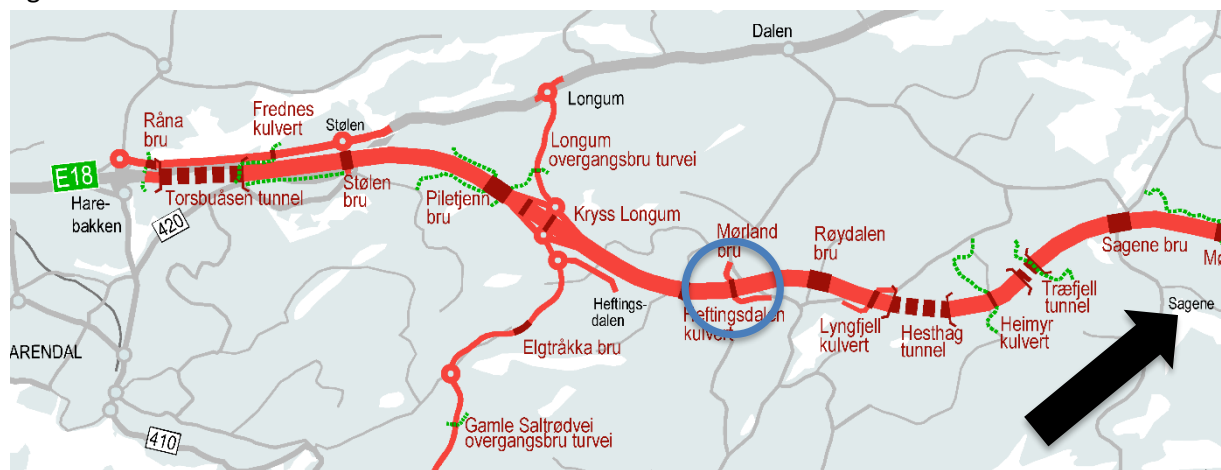
Figure 5–3 Detail look at the new highway, with the circle around Mørland bridge. Dark red lines are bridges and culverts, and the dashed red lines are tunnels. The black arrow shows the approximate north direction [59].
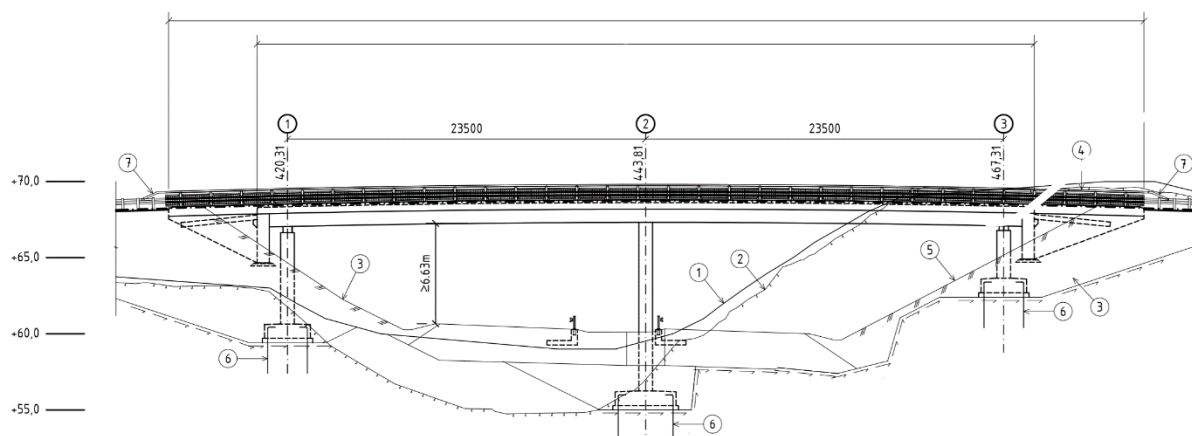
Figure 5–4 Drawing of Mørland bridge. Some measurements have been edited out [60].

The bridge was under construction at the time the group visited, and figure 5-5 shows the state of progress on March 22th.

Figure 5–5 Panoramic picture of Mørland bridge at the time of visit.

6. Method

This project was conducted mainly using qualitative methods, as the opinions and experiences about the subject are pivotal to the conclusion. To answer the research question following methods were utilized [4]:

- Survey to probe existing knowledge of the constructing contractor.
- Interviews, both formal and informal.
- Peer reviews of the project
- Source analysis
  - Literature studies.
- Experiments
  - Constructed a software model of the bridge to get experience and knowledge to base recommendations on.
  - Scan the bridge, and import the scan-data into *ReCap* to register a point cloud and identify its uses for construction documentation and model updates.
  - Use of *Dalux Field* to better quantify its qualities and limits as a complete field management software, and develop a procedure for said use.

All dates in this report are formatted as DD.MM.YYYY.

6.1 Literature studies

The literature study was an ongoing process and was a primary source of information in the preliminary research prior to the survey and interviews. Literature studies were also used to follow up the data from the interviews.

As BIM is relatively new technology and the progress on the field develops rapidly, old sources were considered less relevant. Newer articles were weighed more valid, but all were judged on an individual level.

When searching in a database, the following keywords were used: BIM, Building Information Modeling, 3D Scanning, Reporting, Reporting in the construction industry, Documentation, Documentation in the construction industry, Deviation control, Project management, Issue management, Point cloud, Software. When locating sources, the following databases were primarily used:

WEB OF SCIENCE:
http://apps.webofknowledge.com/WOS_GeneralSearch_input.do?product=WOS&search_mode=GeneralSearch&SID=F4XE9lQINE2qgtYSDqf&preferencesSaved=

GOOGLE: https://www.google.com/

GOOGLE SCHOLAR: https://scholar.google.no/

AUTOMATION IN CONSTRUCTION: https://www.journals.elsevier.com/automation-in-construction

The citation style is IEEE and follows the guidelines found on *Kildekompasset* in conjunction with *EndNote [61, 62]*.

6.1.1 Construction contracts

Through preliminary research and supervision, the contract of a given project was revealed to be a significant decider for BIM in a construction project. Through the external supervisor, the group therefor got access to the contract between *AF Gruppen* and *Kruse Smith*, which is based on the NS 8415 contract standard template. However, as it is a confidential legal document, it could not be cited. In addition to the contract between *AF Gruppen* and *Kruse Smith*, a study of a commentary version of the NS 8405 contract standard was conducted [25].

6.2 Peer review

Throughout this semester, the group has been attending peer reviews for the different topics of the bachelor report. This was an initiative from the internal supervisors at the University of Agder for the projects that were assigned by *Nye Veier*. The primary goal of these sessions was to get healthy discussions regarding the different parts of the report and to gain a better understanding and reflection on what to include and how to write the different topics. These sessions took place every other week.

Before every peer review, each group had to send their presentation to another group for review. The opposing group's task was then to give constructive criticism and feedback about the presentation. This was done to force each group to evaluate their decisions and work methods, and to heighten the quality. This means that every other week each group received a presentation for review. For every presentation, there was a template that every group had to use. The different topics that were presented and discussed were the assignment, introduction, research question, work schedule, method, theory, results, discussion, and conclusion. This was done in eight separate sessions.

After every peer review session, there was time set off to ask the supervisors questions for guidance regarding the assignment.

6.3 Survey

Preliminary to the interviews it was conducted a qualitative survey by e-mail. Through close cooperation with the external supervisor and student peer reviews, it was decided that the tool SurveyXact developed by *Ramboll* with a 5-minute multiple choice survey would be best suited. All questions had the following alternatives; (1) very little, (2) little, (3) large, (4) very large, and (5) do not know. Additionally, there was a sixth alternative where the respondent could answer by text in addition to their graded answer. A few select themes were chosen as a basis for the questions, being BIM, deviation and progress reporting, and Lean construction. Additionally, a few questions regarding the respondent's experience and work position were added at the beginning of the survey.

The survey scheme structure was evaluated through a checklist and document developed by *Statistics Norway* [63], [5], and the question phrasing was evaluated through a table also developed by *Statistics Norway* [64]. The questions and their phrasing were lastly reviewed by a senior engineer at the University of Agder with experience in surveys, and a consulting engineer.

The survey was distributed both to the case-project sub-contractor *Kruse Smith* and to multiple construction companies in Norway through their representatives in the *MEERC Industrialization panel [65]* which would then provide comparable results. To ensure an adequate and representative sample size, the survey was attempted distributed throughout the company hierarchies and across disciplines.

To increase the response rate from *Kruse Smith*, the external supervisor, emphasizing his position as *Director of Technical Division* and the support of the division director at *Kruse Smith*, provided a brief introductory summary of the survey project and why each of the respondents should take their time completing the survey. Other measures to increase the response rate were conducted; deciding on multiple choice and having the same answer alternatives on every question, maximum completion time of five minutes, distributed by e-mail first thing on a Monday, and short questions in Norwegian that kept to the point and did not each span multiple themes.

The survey results were mainly meant to aid and guide in the interview phase, providing some baseline status on some of the assumptions regarding BIM, Lean construction, and reporting. As the survey is to be qualitatively analyzed, giving the rough outlines of the opinions of *Kruse Smith*, and it is only to be an introductory effort followed by more extensive interviews, it was decided that between 20 and 30 respondents would suffice.

6.4 Interviews

The interviews in this project seek to map possibilities and current proficiency about BIM and the use of digital tools in the horizontal construction industry. The data was used qualitative as an initial understanding of the thesis subject, which then was tested and reevaluated further. As thorough interviews take significant time and resources, it was decided to conduct fewer interviews, and instead focus on interview objects which can provide high-quality qualitative information [4]. Interviewees had the choice to remain anonymous, which some objects chose to do. Most of the interviews conducted in the project were structured informal interviews, which the IEEE standard classifies as unpublished work [61].

Utilizing the internal and external supervisors' professional networks, professionals in relevant positions such as discipline leaders and BIM coordinators were contacted through e-mail. Developers of potentially relevant software, such as *Dalux Field*, was also contacted by e-mail. Information was therefore primarily sourced from communication by e-mail early in project research phase. Data from the e-mails were then further researched by methods such as literature studies, tests in software, and further communication by e-mail with new contacts. Thus, the interview objects were chosen based on a combination of strategy, comfort, and snow-ball selection, as explained in the theory chapter.

This expansive research method was used actively to get as much information as possible quickly, as the initial knowledge within the group on the subject matter was limited. Gradually, as the project went from the research phase to the execution/test phase, more structured methods were applied, such as structured formal interviews, surveys, and more extensive literature studies.

Prior to conducting the interviews, a study of the book *Hvordan gjennomføre undersøkelser?* [4] and the book *Metode og oppgaveskriving* [66] was done as an aid in forming the research phase [4, 66]. Initial research was also done on the project subject to guide the project's studies. Due to working within the time and resource constraints of a bachelor project, intensive [4] interviews were deemed

the better alternative, rather than spending the same time and resources on many interviews. Also, even though interviews by Skype or telephone are sometimes more practical and less resource demanding, in-person interviews were prioritized when possible.

To ensure that the interviews are conducted properly and stay reliable, interview-guides were formed and based on templates from Statistics Norway [see appendixes 1-3], [67]. The templates that were originally formed for a lengthy 105-minute interview was changed to a medium length of 50 minutes. The interviews were all based on the same interview guide, with just minor changes in the question line, see Appendix 2 and Appendix 3. It was decided that the interviews should not be recorded, on the assumption that the interviewee would talk more freely and honestly if not being recorded.

The interviewees were selected due to their in-depth knowledge and experience and included professionals from both *Kruse Smith* and *Nye Veier* as well as the project case site E18 *Arendal-Tvedestrand*. Interviewees are in other words strategically selected, to get sufficient data, even with limited resources and time. Only including the structured and formal interviews, it was planned, scheduled, executed, and analyzed a total of three interviews [4].

It was planned for the respective interviewees to vary in the line of work and hierarchy to achieve a response representative of not just one profession. To achieve this, the external- and internal supervisor found suitable interviewees from their networks that matched the terms above, which was then scheduled for in-person interviews.

As the subject and terminology of BIM have a variety of interpretations depending on one's sources, considerations were needed regarding the interviewee's understanding of the topic. The common understanding of words and expressions needed to be taken into consideration during the interview analysis process. In-person interviews with an open dialogue should in this regard, be less prone to misunderstandings on terminology [4]. As such, it was checked that everyone had the same subject terminology understanding.

When scheduling each interview, information regarding the project was sent ahead. Thus, the interviewees could prepare on beforehand, leaving more time for discussion during the 50 minutes. Just before each interview, some information was repeated; the research question was presented, and the planned use of the interview material in the project and that they would be anonymous was clarified.

Two interviewers were present at each interview, this way one could be responsible for writing a minute, while another directed the interview. Thus, the interviewee could have an active dialogue throughout the interview, while there was also an extensive minute to use in the analysis phase. The interviews were somewhat improvised upon, as new topics could come up outside the planned interview guidelines. The improvisation was accepted before each interview and rather encouraged by the interviewer. Question-lines that could lead to new information or new subject topics that the group did not know about were pushed further.

As there were at least two interviewers present at each interview, it allowed for cross-checking the minute and that it was indeed correct, and talk about the impression and interview data. Each interview was reviewed, and the minutes and notes were worked through together the same day to ensure the information was valid. The minute and a written appendix with the intended use of the information was sent by e-mail to the interviewee afterward. That way the interviewee could

approve the representation of them, and that the interview data was correctly understood and written.

The most relevant information was extracted by identifying potential subject threads and researching them further, and claims by the interviewees were checked through literature studies.

Part of the goal of the interviews was to obtain an overview of the functions *Byggeweb Capture* and *Avvik.com* offered. These have been answered by a discipline manager who uses them on a regular basis. See Appendix 9.

6.5 Gathering of software licenses

Initially, a group representative would contact each developer who had a promising software solution, asking for a trial license or an academic license. With each request, it was explicitly explained which contractors were involved in the project, that it was an academic study at the University of Agder, how the software would be tested, and that the software used in the project would be in a favorable position with the contractors involved. This method of license obtainment did not work. Week eight; two weeks before the tests were scheduled, the method shifted. License requests were then made through the internal supervisor as he was in a work position where he could represent the University of Agder and would thus inspire more assistance from the software developers. Already the following week, the group had access to licenses from developers of software for field management, point cloud registering, project management, and later a second point cloud management software. If free trials were publicly available these were used as long as there were no limitations.

6.6 Scanning of the bridge

The bridge was scanned by *Smart Inspection*'s surveyor with the assistance of two group members from the bachelor project, using a *Faro* Focus 330s *LiDAR* scanner. A total of 6 small, white spheres were placed around the site at strategic locations to give the individual scans the ability to find their relative location of each other, enabling a merge the scans into a single point cloud. The scan was conducted on a live site, but most of the work took place during the lunch break. The scans were conducted in a clockwise pattern, using the second-best resolution option and grey scale. Each scan resulted in an FLS file containing the raw data.

6.7 Processing of point cloud

To process the scan data and create a point cloud two software were used, *Scene* and *ReCap*. Several different hardware configurations were used when working on the point cloud data, from a dual-core Intel i5 with 8 GB of RAM, up to very powerful workstations with 64 GB of RAM.

The process was divided into segments and timed to measure the time needed for processing the raw data into a point cloud. The number of segments depending on what software is being used as *ReCap* and *Scene* have very different workflows. A segment starts when human interaction is needed and until the user needs to wait for the software. The time is from the start of the segment and until the software finish the last task. The computer was not used for other tasks while the time tests were done and it was checked in on regularly to see when the tasks were completed.

When recording the time taken to process the point cloud data, the processing took place on a Windows 10 machine with an Intel 3930k CPU overclocked to 4.0 GHz, 16 GB of RAM and a Nvidia 980ti.

6.7.1 Faro Scene

The following workflow was used in *Scene.* First, the raw data folders were dragged and dropped into *Scene.* Then the project was saved, and the scans were preprocessed to create scan point clouds. After the preprocessing was done, spheres and normal planes were marked and identified with corresponding names. After the preprocessing was done the white spheres, and planes on the pillars or abutments were marked and identified in the planar view, and corresponding names were added. Figure 6-1 shows how it looked like when marking spheres.
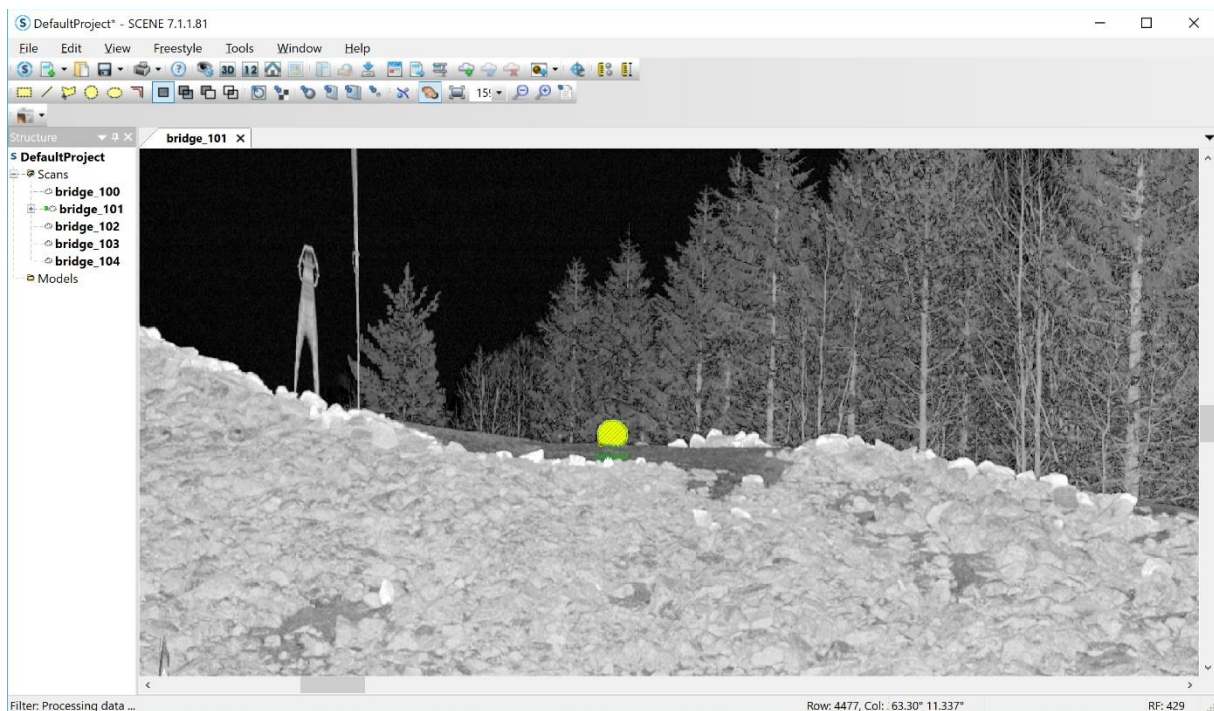

Figure 6–1 How it looked like when a sphere was marked in Scene

The next step was to register the scans with the *Place scans* option. Checkerboard normals were not used for placing the scans, but correspondence search was enabled. Before the final placement of the scans, the *Mean Target Distance error* was minimized by setting anti-correspondence on matches with low accuracy. When timing the process, a rough cleanup of excess points was done using the box and deleting points outside it. Then the point cloud was exported as a *ReCap* project using XYZ settings, to make it compatible with *Verity*.

6.7.2 ReCap

When processing the scan data in *ReCap* the following workflow and settings were used. A new project was created in *ReCap* 2018 or 2019 and the raw scan data FLS files where manually dragged and dropped into *ReCap*. A clipping range of 0m-120m was used with an intensity clipping of 0%-100% and an aggressive filter scan. In the advanced menu a decimation grid of either 0mm, 25mm or 50mm was used, with a higher value resulting in smaller file size. Using a value of 10mm-50mm for the decimation grid was recommended by *ClearEdge3D* to improve *Verity's* performance[68, p. 2]. Every option for axis remained at the default selections.[68, p. 2].

To register the individual scan data into a combined data set a combination of automatic and manual registration was used. This was done by registering the white spheres in different views and telling *ReCap* how they correlated. This is how *ReCap* know how the scan data are placed relative to each other. Few to none steps were taken to improve or edit the accuracy of the point cloud.

6.8 Creating a Revit model of the bridge

To ensure that we had a model of the bridge that the point cloud could be compared against, a model was created in *Revit*. The model created was made from drawings supplied by *Kruse Smith* and made using *Revit* families with the intent of having parametric elements. To learn how to use and create parametric *Revit* families a guide from *Autodesk* University was used.

The resource for learning how to use and create parametric *Revit* families was the guide from *Paul Aubin* named *Revit Families: A Step-by-Step Introduction* found on *Autodesk University*, and troubleshooting using Google [69].

6.9 Deviation control

For the deviation control, it was planned to use both *PointSense* and *Verity*, as both software can measure the deviation between the point cloud and model and create a heat map to show the deviation visually. To achieve a procedure for deviation control both the theory chapter "Comparing point cloud to a model" and the features of software were examined and discussed.

6.9.1 PointSense

PointSense was learned by using a trial version. The planned method was to link the point cloud to the *Revit* model in *Revit.* Then aligning the point cloud to the *Revit* model with use of sections and visually check chosen control points for the correct position of the model and point cloud. When the adequate position of both the model and point cloud was achieved, the heat map tool within *PointSense* would have been used to create a heat map of the deviation from the point cloud to the model, to check for elements out of tolerance. However, the group could not utilize *PointSense* for the deviation control check because the trial expired before the point cloud data of the bridge was received.

6.9.2 Visual inspection using Revit

The visual inspection was done in *Revit* and comprised of taking cross-sectional cuts with minimal view range. Then the position of the point cloud and the model was checked to see if it was a complete overlap, indicating no deviation, or if there was a difference, indicating a deviation.

To be able to perform the inspection, the point cloud was linked into the *Revit* model using the origin to origin option and then moving the middle column of the point cloud to fit the corresponding column in the model. This does not take into consideration if the bridge is placed wrongly, it only checks if the relative position of the elements and their geometry is correct.

6.9.3 Verity

To ensure the proper use of *Verity* an hour introduction meeting was held by a *ClearEdge3D* salesman along with the study of *Verity user guide* in appendix 19 and online tutorial videos [50].

To test *Verity* as a documentation software and to see if the bridge was built accordingly to the as-design model a set of four different analyses was conducted. The analyses had different methods for

positioning the point cloud to the model. The reason for the four analyses is to see if it is plausible to achieve the same position for the point cloud and model without the global coordinates. The results of total translation from the analyses will be discussed as this is the translation that is compared to the user-defined tolerance to conclude if the element passes the analyses. The other results of translation are shown to understand how the as-designed element is orientated in the x, y, and z-axis according to the as-built element. The result of rotations will be included in the appendix and will not be a part of the discussion.

The analyses will be named analysis 1, analysis 2, analysis 3 and analysis 4 for a more transparent overview of the report. Analysis 1 will be the analysis of the manually moved model to the point cloud. Analysis 2 will be the analysis of positioning the point cloud with the use of three survey points. Analysis 3 will be the analysis of positioning the point cloud with the use of six survey points. Analysis 4 will be the analysis of moving the host item to its as-built position.

The model used in the analyses is a DWG model of *Mørland* Bridge retrieved from *Kruse Smith*. In addition, there has been created a *Revit* model. However, to minimize the risk for self-made errors the DWG model will be the model used to check if the as-built point cloud is built accordingly to as-designed model. The *Revit* model will be used to test if there is a possibility to update the *Revit* model to as-built automatically.

The model elements used for the analysis are the columns, the abutments, the barriers without railing and the superstructure. The point cloud used is the *ReCap* project file with decimation set to 50mm.

All the analyses in *Verity* were done with the same settings. Display units were set to be in mm, (millimeters) and the tolerance was set to be 15mm. The model elements and the point cloud used for the analysis was added to *Verity* by selecting the elements and the point cloud, and the tool *add to Verity (search tree)* was used. After the analysis was complete none of the elements in *Verity* were modified to alter the results.

Manual placement of the model and the point cloud was done by importing both into *Navisworks*. The model was then moved with the move and rotate tools in *Navisworks* to the point cloud by focusing on the alignment of the middle column of the model to the middle column of the point cloud. Then, for more accurate alignment of the middle column the measure tools *measure point to point* and *measure angle* was used in relationship with *transform selected item*. The final step was to rotate the model to align the point cloud to the south and west abutment.

The positioning of the model and point cloud with three and six survey points was done by using *Navisworks* and *ReCap*. For the point cloud with three survey points, three points were selected in *Navisworks*, and the coordinates were taken from the tab *measure tools* under *windows*. Then the coordinates were entered as survey points in the registration process of *ReCap* with the same locations of the three points in *Navisworks*. The same procedure was done with positioning the model and point cloud with six survey points. Except there was taken coordinates from six points in *Navisworks*, and the coordinates for the same six points were added to *ReCap*.

The positioning when moving elements to as built were done after running the analysis with six survey points. After the analysis, model elements were moved to *Verity's* placement of the copied elements fitted to the point cloud. The operation was done with the *Verity* tool *move host item to as-built*.

6.10   Updating the Revit model

To update the *Revit* model from as designed to as built, the *Revit* model was loaded in *Revit*, and the point cloud was linked. After this the point cloud was positioned relative to the center column and the underside of the bridge superstructure, assuming that this was a correct placement.

6.11   Model-based tests

The goal with the model-based tests is to get firsthand experience on how it is to do model-based documentation and reporting. To ensure that our inexperience with modeling impacts the thesis project as little as possible, we will interview two professionals in *Kruse Smith* who have in-depth knowledge about modeling. In addition to this, we will search for guidelines on how to correctly build a model and conduct tests.

When using the point cloud data, we need to know what degree of accuracy we have and how much we can trust the data.

When conducting model-based tests for reporting on deviation during the construction phase of a project, *Dalux Field* was the chosen software. *Kruse Smith* did not have any internal analysis on which field manager software to implement, and no statistics or evaluations supporting any specific software solution other than the one they already used.

Results from the interviews regarding functions for *Byggeweb Capture* and *Avvik.com* were used to compare the results from the *Dalux Field* tests. This was then organized in a table to make a clear and systematic comparison.

We evaluated how the functions of *Dalux Field*, *Byggeweb Capture,* and *Avvik.com* fitted the desired procedure for model-based reporting by making a checklist of features for each software. This checklist was part of the result and a base for the discussion. The points on the checklist represented the most significant internal factors. External factors were primarily based on interviews and literature studies.

To ensure sufficient competence in *Dalux Field*, a Skype meeting with *Dalux AS* were held. During this meeting issues with models, enterprises and tasks were addressed. Also, any questions remaining unanswered after the meeting were replied to on e-mail post meeting by *Dalux* [Appendix 22].

6.11.1   The use of Dalux Field

To secure the credibility of the tests in *Dalux Field*, we created a project execution model. The first step is to create the enterprises necessary and delegate ranks within the organization. The second step is to import the *Revit* (IFC) file along with the associated floor plans. The embedded viewer is then used to navigate in the construction and to register a deviation report. Furthermore, we will evaluate the layout of the report to find strengths and weaknesses. We will then test how the report will be answered and handled in the program. This test was conducted on different types of reports, and the evaluation of strengths and weaknesses were done as well. Finally, these results were compared to the process of *Avvik.com* and *Byggeweb Capture*. The evaluated aspects were reviewed in the form of a table in the results chapter. Which of the aspects to point out were discussed in the interview with *Kruse Smith* with a BIM-coordinator and a Discipline leader.

Execution model:

1. Establish an enterprise
2. Import the model and drawings
3. Create a deviation report
4. Evaluate the report layout regarding strengths and weaknesses
5. Reply to the report from a project management position
6. Evaluate the response quality
7. Repeat the same procedure for different types of tasks/reports
8. Evaluate strengths and weaknesses of different tasks/reports
9. Compare general report quality to *Avvik.com* and *Byggeweb Capture*

This procedure was conducted by using a model of a building to analyze the potential of *Dalux Field* in the vertical construction industry. Furthermore, the same procedure was then conducted by using a bridge model to observe any eventual quality loss for use in the horizontal construction industry. [Appendix 23]

Pictures for documentation from *Dalux Field* was taken by the group, and not gathered from the internet or other sources.

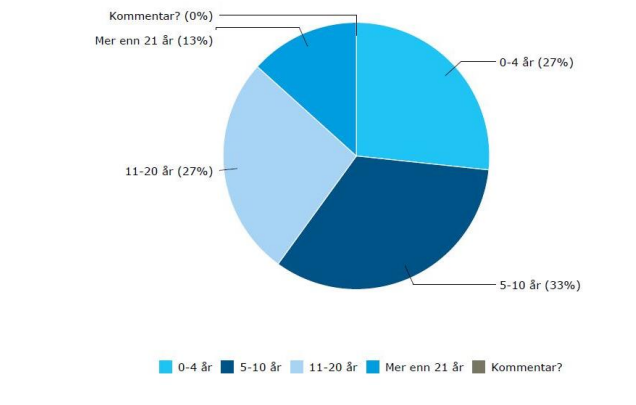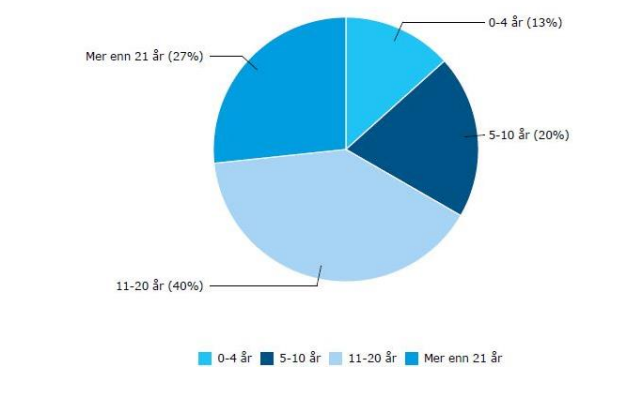|		
	What is your work position? 100% contractor	What is your work position? 60% consulting engineer; 20% contractor; 7% contracting client; 7% facility manager; 7% other
2.		
	How long have you been work active in the horizontal construction industry? 27% 0-4 years; 33% 5-10 years; 27% 11-20 years; 13% over 21 years;	How long have you been work active in the horizontal construction industry? 13% 0-4 years; 20% 5-10 years; 40% 11-20 years; 27% over 21 years;
3.		
	How would you evaluate your personal digital competence? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know	How would you evaluate your personal digital competence? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know

4.	I hvilken grad anser du din digitale kunnskap? Vet ikke (0%) Kommentar? (0%) Veldig stor (13%) Stor (27%) Middels (53%) Veldig liten (0%) Liten (7%) ■ Veldig liten ■ Liten ■ Middels ■ Stor ■ Veldig stor ■ Vet ikke ■ Kommentar?	I hvilken grad anser du din digitale kunnskap? Vet ikke (0%) Veldig stor (40%) Veldig liten (0%) Liten (0%) Middels (7%) Stor (53%) ■ Veldig liten ■ Liten ■ Middels ■ Stor ■ Veldig stor ■ Vet ikke
	To what degree is digital solutions used in your firm? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know	To what degree is digital solutions used in your firm? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know
5.	I hvilken grad blir digitale løsninger brukt i ditt firma? Kommentar? (6%) Veldig stor (0%) Vet ikke (0%) Stor (24%) Middels (65%) Veldig liten (0%) Liten (6%) ■ Veldig liten ■ Liten ■ Middels ■ Stor ■ Veldig stor ■ Vet ikke ■ Kommentar?	I hvilken grad blir digitale løsninger brukt i ditt firma? Vet ikke (0%) Veldig stor (57%) Veldig liten (0%) Liten (0%) Middels (29%) Stor (14%) ■ Veldig liten ■ Liten ■ Middels ■ Stor ■ Veldig stor ■ Vet ikke
	In which medium is your work presented? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know	In which medium is your work presented? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know

6.	**I hvilket format presenteres ditt arbeid?** Kommentar? (0%) · Ikke relevant (16%) · Modell som dokumentasjon og resultat (0%) · BIM-modell med tegninger og beskrivelser i tillegg (26%) · Arbeidstegninger og beskrivelser (58%) — Legend: Modell som dokumentasjon og resultat / BIM-modell med tegninger og beskrivelser i tillegg / Arbeidstegninger og beskrivelser / Ikke relevant / Kommentar?	**I hvilket format presenteres ditt arbeid?** Ikke relevant (21%) · Modell som dokumentasjon og resultat (14%) · Arbeidstegninger og beskrivelser (7%) · BIM-modell med tegninger og beskrivelser i tillegg (57%) — Legend: Modell som dokumentasjon og resultat / BIM-modell med tegninger og beskrivelser i tillegg / Arbeidstegninger og beskrivelser / Ikke relevant
	Would you say that you know what BIM is? 88% yes, 12% no	Would you say that you know what BIM is? 100% yes
7.	**Vil du påstå at du vet hva BIM innebærer?** Kommentar (0%) · Nei (12%) · Ja (88%) — Legend: Ja / Nei / Kommentar	**Vil du påstå at du vet hva BIM innebærer?** Nei (0%) · Ja (100%) — Legend: Ja / Nei
	To what extent are you satisfied with the use of BIM compared to construction projects without BIM? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know	To what extent are you satisfied with the use of BIM compared to construction projects without BIM? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know

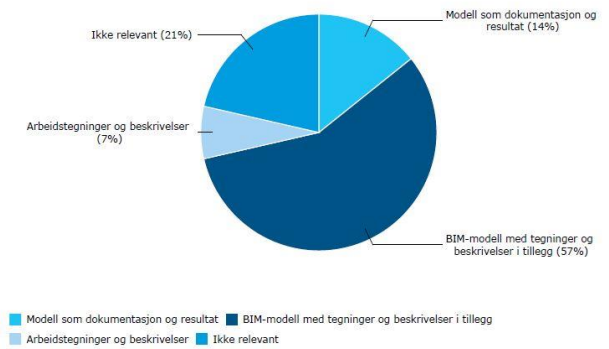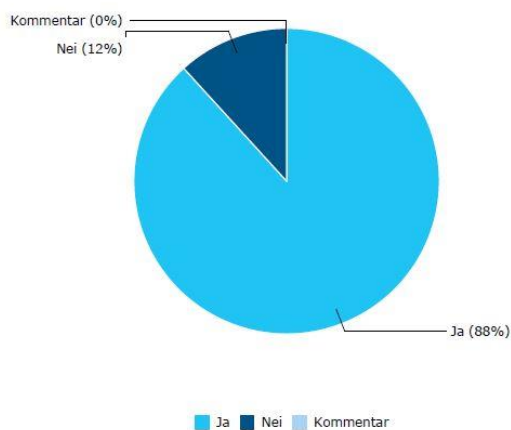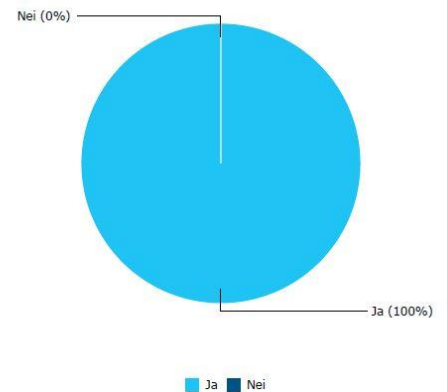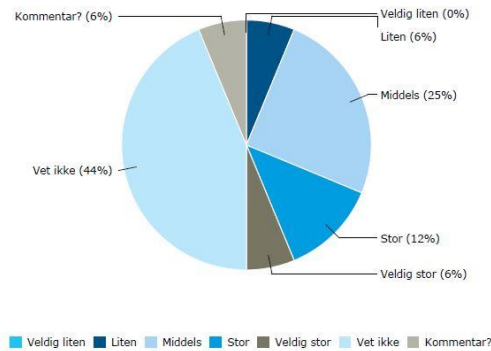| 8.	I hvilken grad er du fornøyd med bruk av BIM sammenlignet med byggeprosesser der BIM ikke brukes? Kommentar? (6%) Veldig liten (0%) Liten (6%) Middels (25%) Vet ikke (44%) Stor (12%) Veldig stor (6%) ■ Veldig liten ■ Liten ■ Middels ■ Stor ■ Veldig stor ■ Vet ikke ■ Kommentar?	I hvilken grad er du fornøyd med bruk av BIM sammenlignet med byggeprosesser der BIM ikke brukes? Vet ikke (7%) Veldig liten (0%) Liten (14%) Middels (14%) Veldig stor (43%) Stor (21%) ■ Veldig liten ■ Liten ■ Middels ■ Stor ■ Veldig stor ■ Vet ikke
	To what extent is BIM used in your workplace? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know	To what extent is BIM used in your workplace? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know
9.	I hvilken grad benyttes BIM på arbeidsplassen din? Kommentar? (6%) Veldig stor (0%) Vet ikke (0%) Stor (6%) Middels (12%) Veldig liten (50%) Liten (25%)	I hvilken grad benyttes BIM på arbeidsplassen din? Vet ikke (0%) Veldig liten (0%) Veldig stor (14%) Liten (7%) Stor (29%) Middels (50%) ■ Veldig liten ■ Liten ■ Middels ■ Stor ■ Veldig stor ■ Vet ikke
	to what extent have you been offered lessons in BIM? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know	to what extent have you been offered lessons in BIM? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know

10.

I hvilken grad har du fått tilbud om opplæring i BIM?

Kommentar? (6%)
Vet ikke (6%)
Veldig stor (0%)
Stor (12%)
Middels (0%)
Liten (19%)
Veldig liten (56%)

Veldig liten ■ Liten ■ Middels ■ Stor ■ Veldig stor ■ Vet ikke ■ Kommentar?

I hvilken grad har du fått tilbud om opplæring i BIM?

Vet ikke (7%)
Veldig stor (14%)
Stor (21%)
Veldig liten (21%)
Liten (21%)
Middels (14%)

Veldig liten ■ Liten ■ Middels ■ Stor ■ Veldig stor ■ Vet ikke

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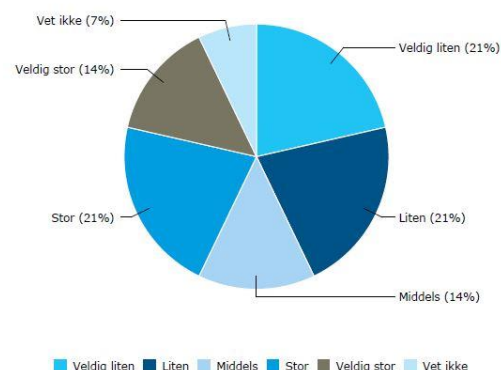
To what degree would you say today's system for schedule reporting works? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know

To what degree would you say today's system for schedule reporting works? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know

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11.

I hvilken grad syns du dagens system for framdriftsrapportering fungerer?
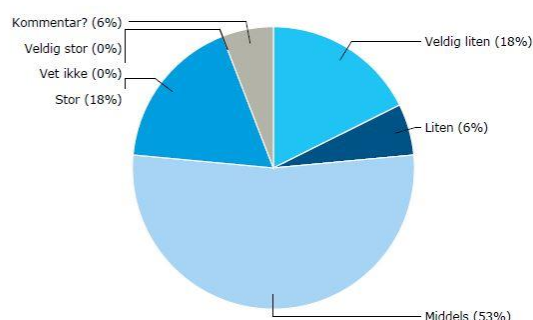
Kommentar? (6%)
Veldig stor (0%)
Vet ikke (0%)
Stor (18%)
Veldig liten (18%)
Liten (6%)
Middels (53%)

I hvilken grad syns du dagens system for framdriftsrapportering fungerer?

Vet ikke (7%)
Veldig stor (0%)
Stor (7%)
Veldig liten (0%)
Liten (29%)
Middels (57%)

Veldig liten ■ Liten ■ Middels ■ Stor ■ Veldig stor ■ Vet ikke

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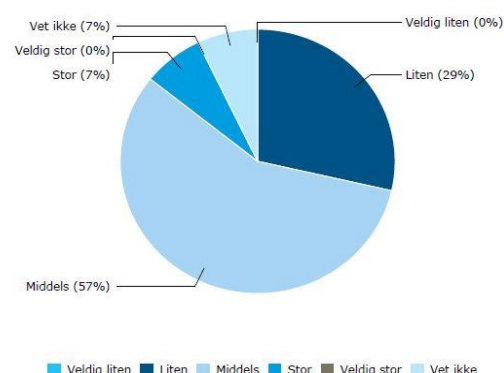
To what degree would you say today's system for deviation reporting works? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know

To what degree would you say today's system for deviation reporting works? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know

12.	I hvilken grad fungerer dagens system for rapportering av avvik og endringer på arbeidsplassen din?	I hvilken grad fungerer dagens system for rapportering av avvik og endringer på arbeidsplassen din?
	To what degree do you think Lean Construction/Involving Planning would be of help to your workplace? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know	To what degree do you think Lean Construction/Involving Planning would be of help to your workplace? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know
13.	I hvilken grad tror du integrering av Lean Construction/Involverende planlegging vil være til hjelp for arbeidsplassen din?	I hvilken grad tror du integrering av Lean Construction/Involverende planlegging vil være til hjelp for arbeidsplassen din?
	To what extent is Lean Construction affecting your work today? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know	To what extent is Lean Construction affecting your work today? From left to right: (1) very little, (2) little, (3) medium, (4) large, (5) very large, (6) do not know

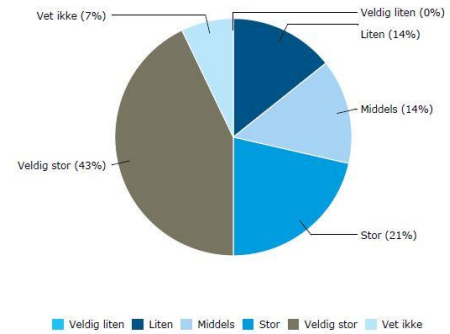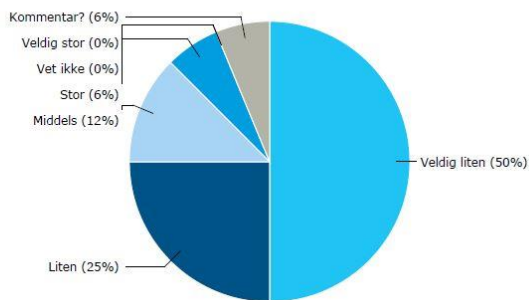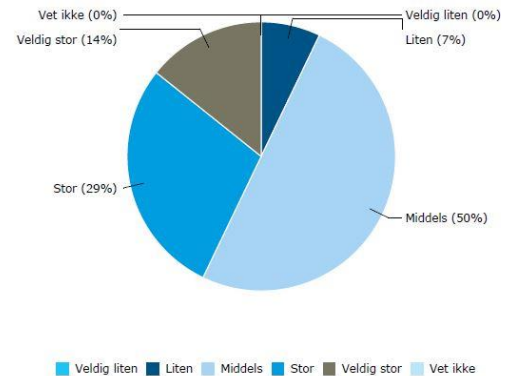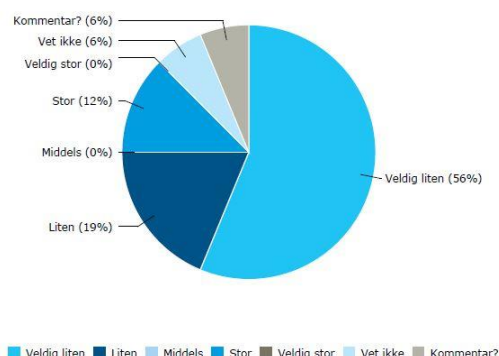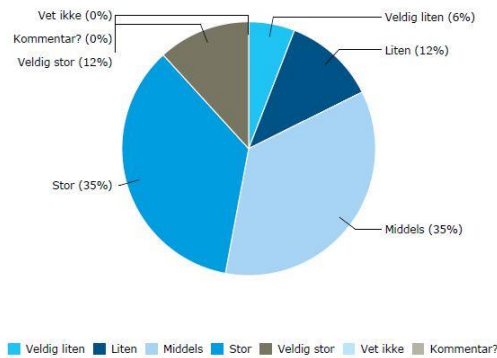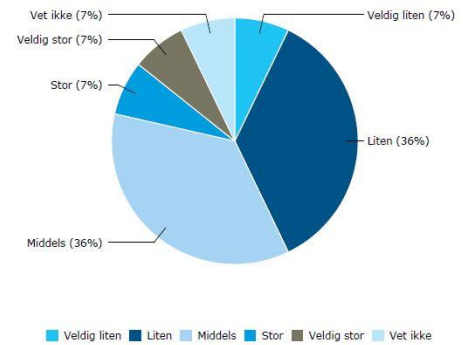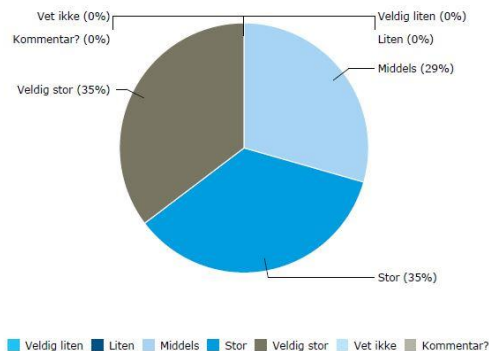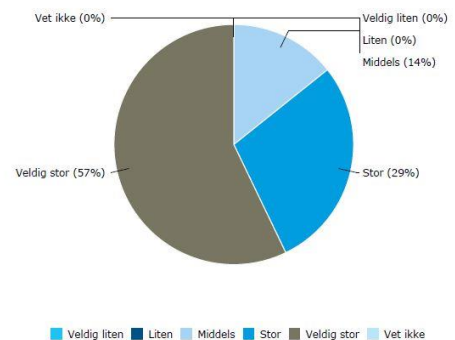| 14.	I hvilken grad har Lean Construction-prinsipper innvirkning på arbeidet ditt i dag?	I hvilken grad har Lean Construction-prinsipper innvirkning på arbeidet ditt i dag?
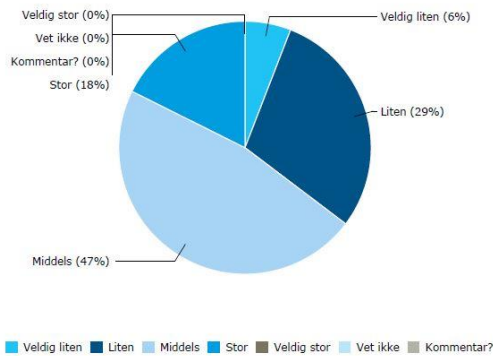
Left chart labels: Veldig stor (0%), Vet ikke (0%), Kommentar? (0%), Stor (18%), Veldig liten (6%), Liten (29%), Middels (47%). Legend: Veldig liten, Liten, Middels, Stor, Veldig stor, Vet ikke, Kommentar?

Right chart labels: Vet ikke (0%), Veldig stor (14%), Veldig liten (7%), Liten (21%), Stor (21%), Middels (36%). Legend: Veldig liten, Liten, Middels, Stor, Veldig stor, Vet ikke
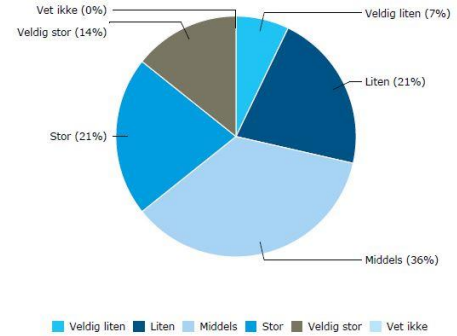
Tabell 7-1 Pie charts from the multiple choice survey. The left column is the results from Kruse Smith [Appendix 6], and the right column are the results from Construction Industry [Appendix 7]. Questions are translated into English in the row above the charts.

7.2 BIM model of the bridge

The process of creating an exact *Revit* model of the bridge from drawings was difficult. A bridge has more complex geometry than a typical building, and to create an accurate parametric model takes considerable skill. The snap function in *Revit* was especially troublesome when working on very large elements. The outer columns of the bridge have a height difference of 35mm over a length of 47m. When trying to create the bridge at the correct height, *Revit* either snap to the horizontal axis or minimum 1 degree, making it impossible to get a correct slope. To circumvent this snapping had to be disabled. Figure 7-1 shows the closest it was possible to get to the horizontal line, at the intersection between the black curve and the dotted line, before snapping to said point.
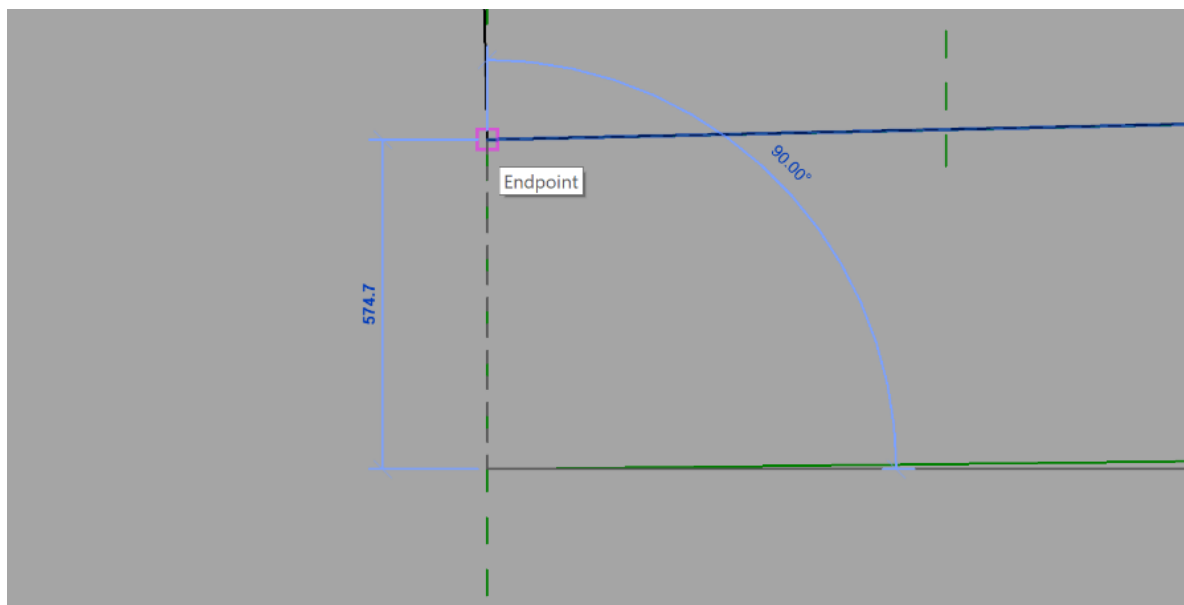
Figure 7–1 Closest distance from the horizontal snap one could get in Revit before snapping.

The model ended up with four different element types; column, foundation, abutment and the bridge superstructure containing both deck slab and barrier. Creating the columns, foundation, and abutment as parametric elements were feasible with some training and troubleshooting but creating a parametric bridge superstructure proved to be very challenging and it ended up as a non-

parametric element. This means that changes to the bridge design with this model would require more effort compared to if the bridge was fully parametric.

7.3 Scanning the bridge

The process of scanning the bridge consisted of 5 scans and ended up taking approximately 60 minutes from start to finish, with 30 minutes of actual scan time. Because of where the optimal placement of scanners was there where some traffic close to the scanner during the process, but measures were done to ensure this had minimal impact on the results.

7.4 Processing of point cloud

There was a variable CPU utilization during the process on all hardware configuration, ranging from 15% towards 100% while the software was processing the point clouds. Most of the time spent working on the point clouds was to wait for the software to finish its processing. Because the project where relatively small with only five scans, RAM did not appear to be a bottleneck even with as little as 16 GB.

For this project, the group's lack of experience did not appear to be a significant obstacle.

7.4.1   Faro Scene

Faro Scene has two User Interface (UI) settings, new and old, where the new UI is an effort in streamlining and simplifying the experience. It does this by combining several processes into one, at the expense of clarity. There were some issues in getting the new UI to work correctly, and at the advice of *Smart Inspection,* the old UI was used[72]. Figure 7-2 shows the difference between the old and the new UI
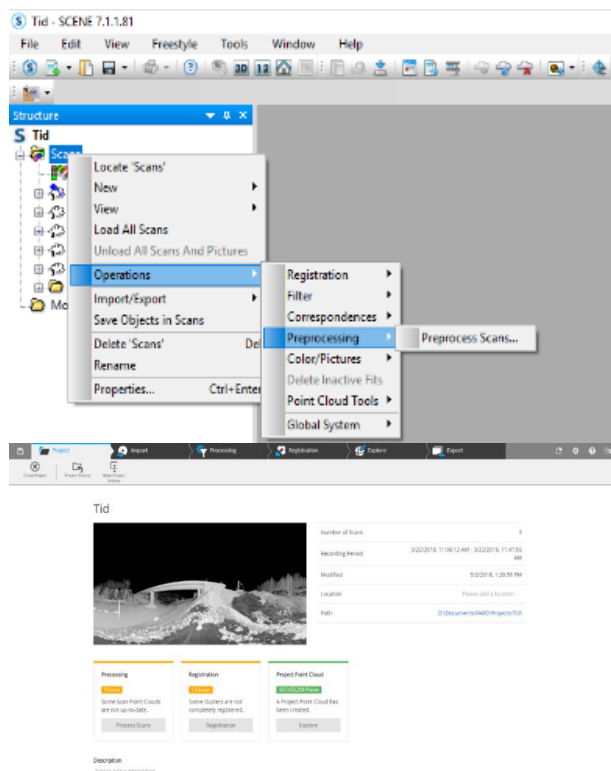
Figure 7–2 The old UI (top) vs. the new UI (bottom).

While *Scene* provides many settings and is relatively complicated, with the help of a tutorial on YouTube provided by *Smart Inspection* it was possible to get a basic competence level in one day.

The total time for getting a project exported to *ReCap* was 3 hours and 31 minutes, where approximately 20 to 30 min of this was active work, and the rest was waiting for the software to finish. Table 7-1 shows how the time was divided into preprocessing, registering, and exporting. The table does not take every process into the calculation, only the large sections, and as such, the total time is longer than seen here but not by much.

Preprocessing	55 minutes
Registering	13 minutes
Exporting	125 minutes
Total time	3 hours and 31 minutes

Table 7-1 Time data for processing point cloud in Scene.

The result was a point cloud with a mean deviation of under 5 mm as seen in figure 7-3. If higher precision is needed, this could be solved by adding additional reference points between the scans, in the form of either spheres or checkerboard stickers.
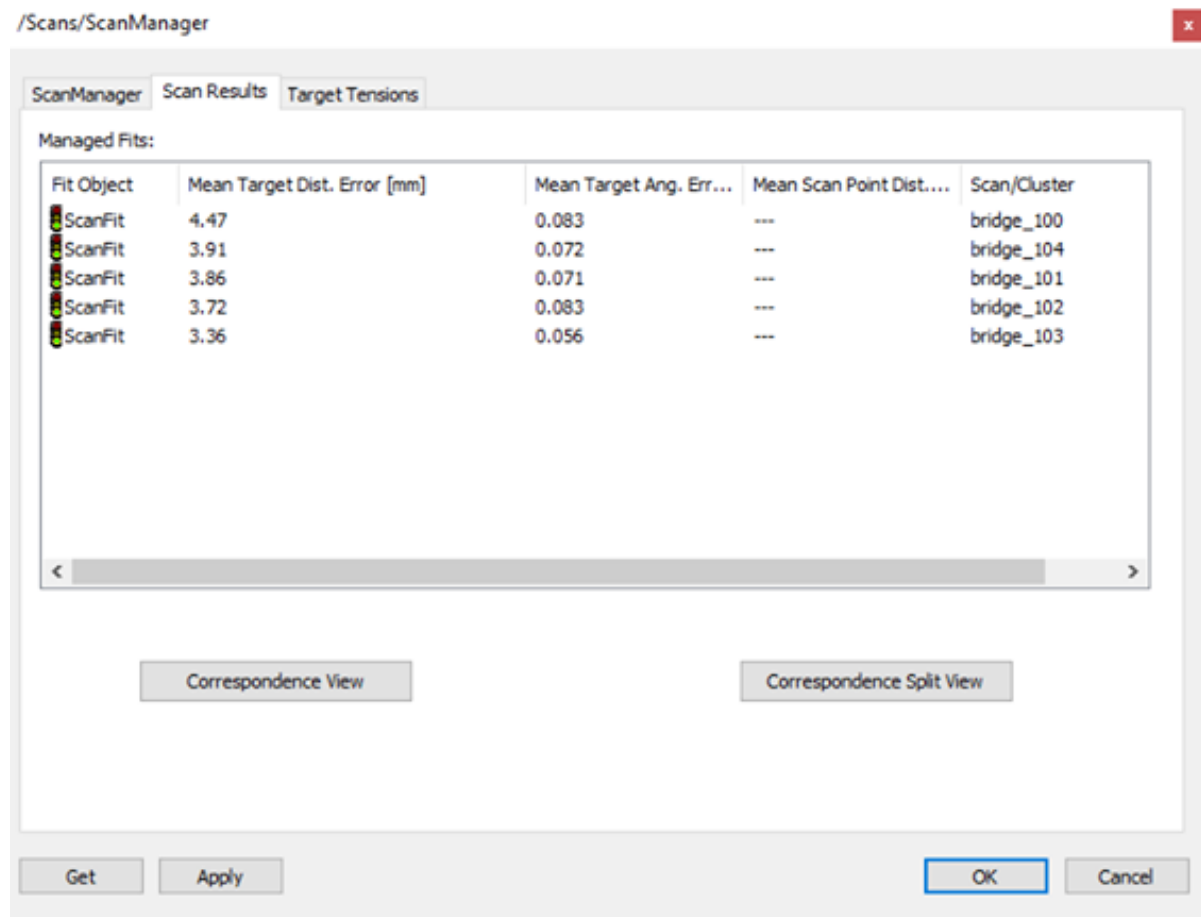
Figure 7–3 Accuracy of the final point cloud in Scene.

The finished point cloud is seen in figure 7-4. A very rough removal of unnecessary points where done to increase performance and clarity.
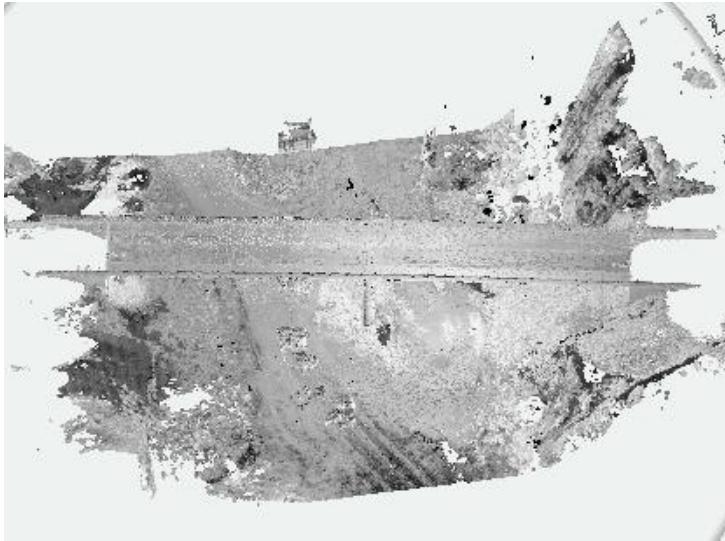
Figure 7–4 Picture of the final point cloud as seen in Scene.

7.4.2 Autodesk ReCap

ReCap has a more straightforward UI than *Scene* and has a lot fewer settings to change. This gives the impression of *ReCap* being a more accessible program to learn. This impression is in some ways correct as *ReCap* needs fewer steps to get a finished point cloud, and gives the user fewer settings to chose from, as seen in Figure 7-5 shows an example of the *ReCap* UI and how it appears very user-friendly.
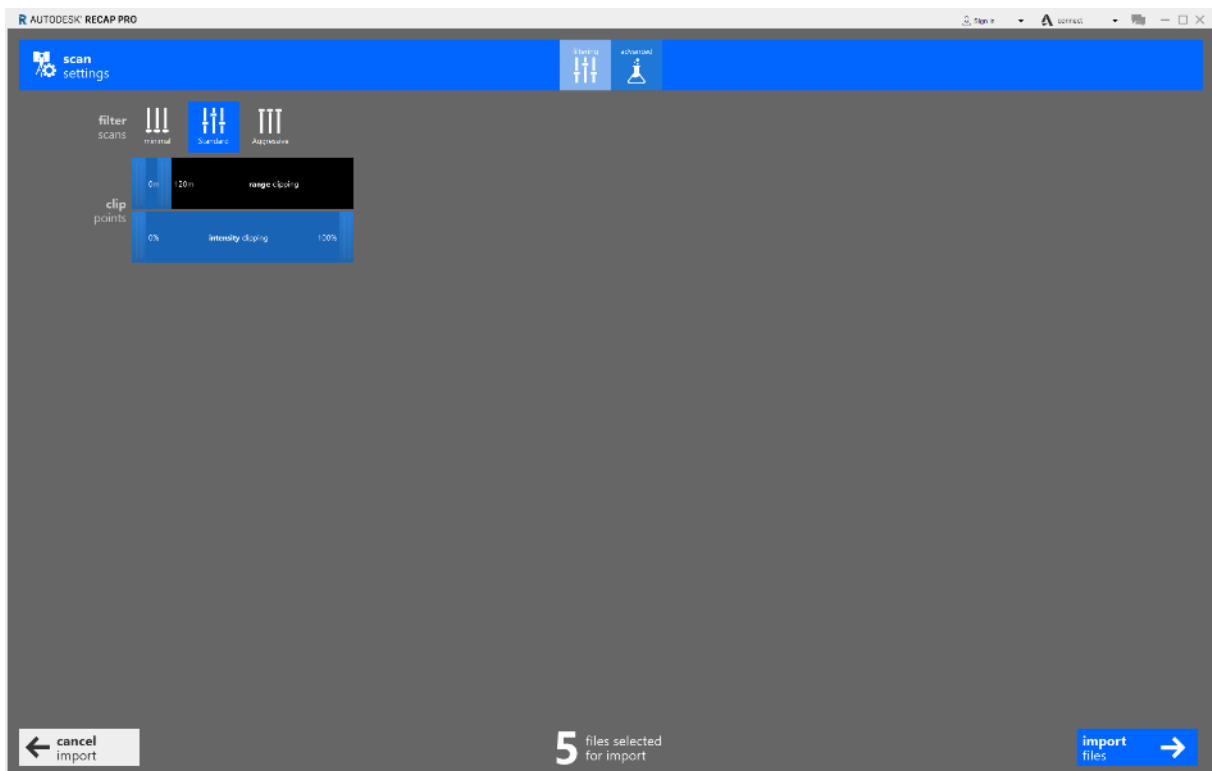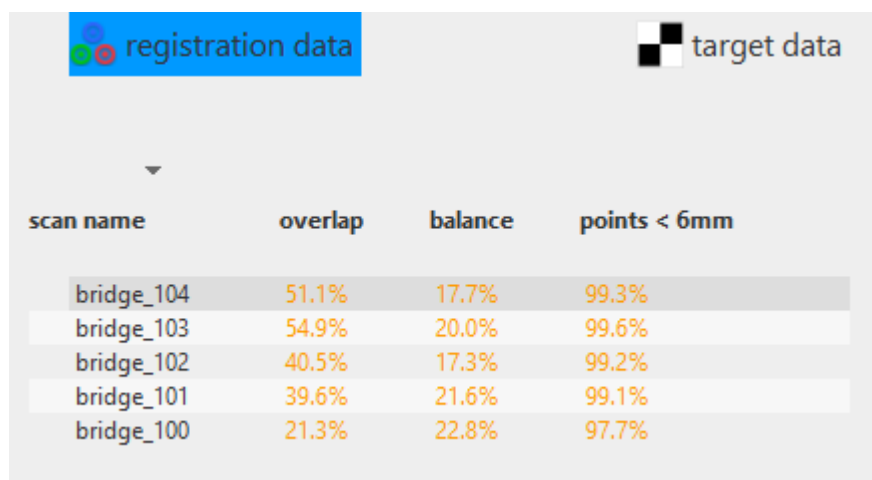
Figure 7–5 The ReCap UI and options when importing point clouds.

The total time it took to process the set of point clouds in *ReCap* was 2 hours and 33 minutes. Table 7-2 shows how long the individual actions took. The settings for *ReCap* when taking the time was aggressive cleaning, 0m-120m range clipping, 0%-100% intensity clipping and 50mm decimation grid.

Import time	116 minutes
Registering time	5 minutes
Index time	32 minutes
Total time	2 hours and 33 minutes

Table 7-2 Results of the time it took for processing the point cloud. As seen here the majority of the time was spent waiting for the import to finish.

The result is a point cloud where a majority of the points have an accuracy of 6mm or lower, as seen in figure 7-6

Figure 7–6 Registration report in ReCap. It is available after the registration is complete and can always be accessed while in the project.

7.5 Documenting the bridge

Based on the tests, and findings in the literature study, figure 7-7 shows the recommended procedure for deviation documenting of the bridge.
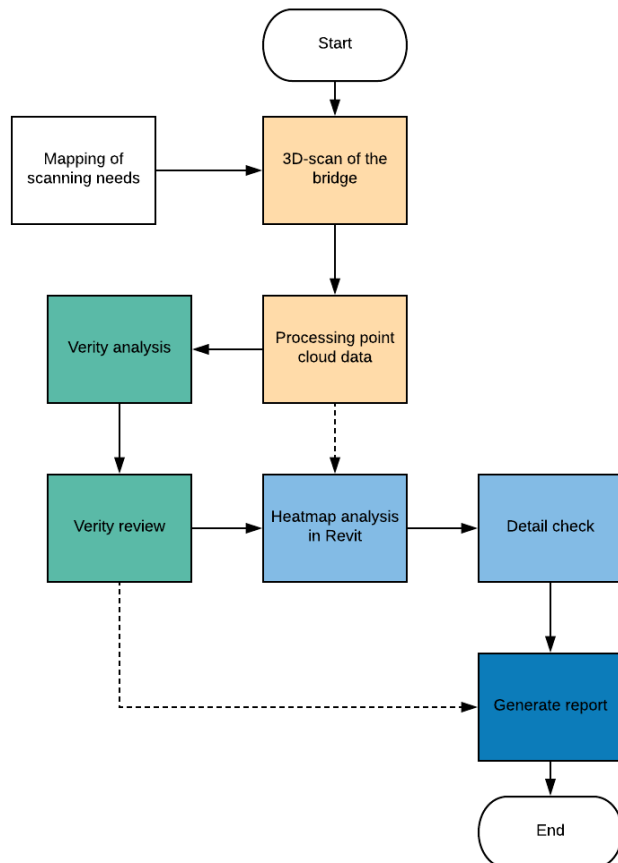
Figure 7–7 The whole lines are the recommended workflow for documenting Mørland bridge. The dotted line are alternative ways.

As shown in figure 7-7, the documentation can be done in three different ways. However, the recommended procedure is the one following the complete lines in figure 7-7 and consist of eight steps.

Step 1: *Mapping of scanning needs* is an easily overlooked, but important step. This step is to ensure that the point cloud contains all the needed data and other needs that the customer has.

Step 2: *3D-scan of the bridge* is the act of scanning the bridge.

Step 3: *Processing of point cloud data* is where the point clouds are systematically put together to be a complete 3D representation of the as built. In this step, the point cloud is processed, registered and indexed. Insertion of survey points can be done in the registration process.

Step 4: *Verity analysis* is to import both model and point cloud into *Navisworks* with the same global coordinates. Then run the *Verity* analysis to get an overview of the installations statutes of the elements in the model.

Step 5: *Verity review* is to check and review the elements in *Verity,* manipulations to the as-built can be done in this step if necessary. Reviewing the elements means to visual check every element and mark it as reviewed by whom and if there are any actions required for the element. Then report from *Verity* are to be created at the end of the *Verity* review.

Step 6: *Heat map analysis in Revit* is to create a heat map analysis so one can get an overview of whether the point cloud fits the model adequately and to look for what elements with a deviation beyond the tolerance.

Step 7: *Detail check* is a detailed check that will use the report from *Verity* along with the heat map analysis from *Revit* to do detail checks of the elements that did not pass the analysis from *Verity* or did stand out in the heat map analysis in *Revit*. The detail checks are to be done in sections to better see the positioning of the point cloud to the model.

Step 8: *Generate report* is to generate a report containing all the relevant information and images of all the elements that did pass or did not pass the analysis.

The two other recommended procedures exclude parts of the recommended method, but can still be used to document the bridge, but without as much credibility. These two procedures are shown in the same figure 7-7 as striped lines.

7.5.1   PointSense

Efforts were made to get *Faro PointSense*, but the University of Agder could not defend the cost associated with the software when there was only one group who would benefit from it. A 14-day trial version of *PointSense* for *Revit®* was supplied to the group before the bridge was scanned. This meant that the group could not do a heat map analysis of the deviations between the point cloud and model when documenting the bridge.

7.5.2   Visual inspection with Revit

Using *Revit* for a visual detail check was tolerable but should be paired with other methods to increase efficiency. Because the model and point cloud had different global coordinates, there was a need to manually place both models correctly, as demonstrated in figure 7-8.
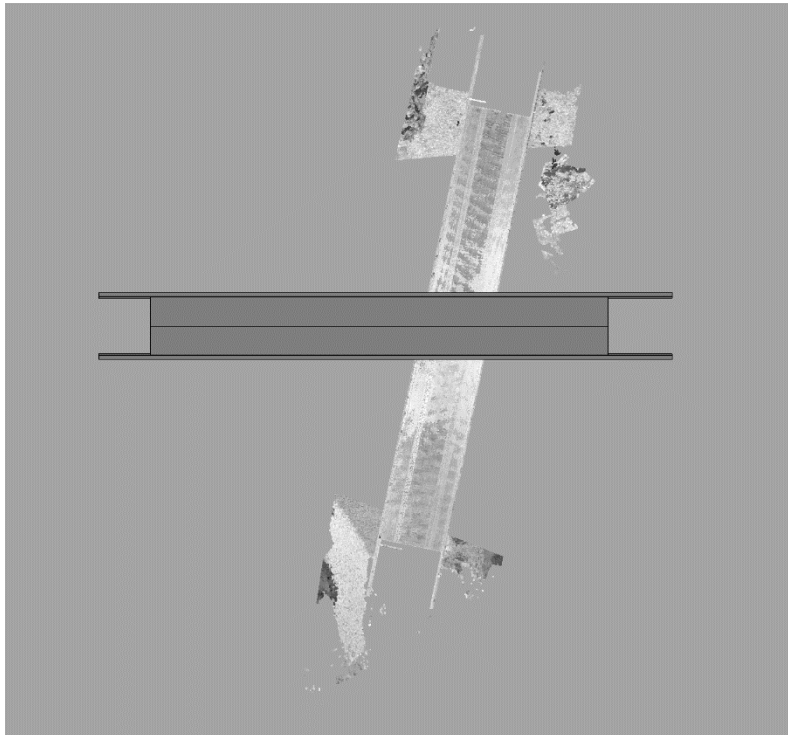
Figure 7–8 The coordinate systems of the model and point cloud is different, as seen by their original placement in Revit.

Figure 7-9 shows a deviation found during the inspection, where the blue is the *Revit* model, and the red line is the point cloud. After investigating why there was a difference, the error was found to be because of a modeling error.
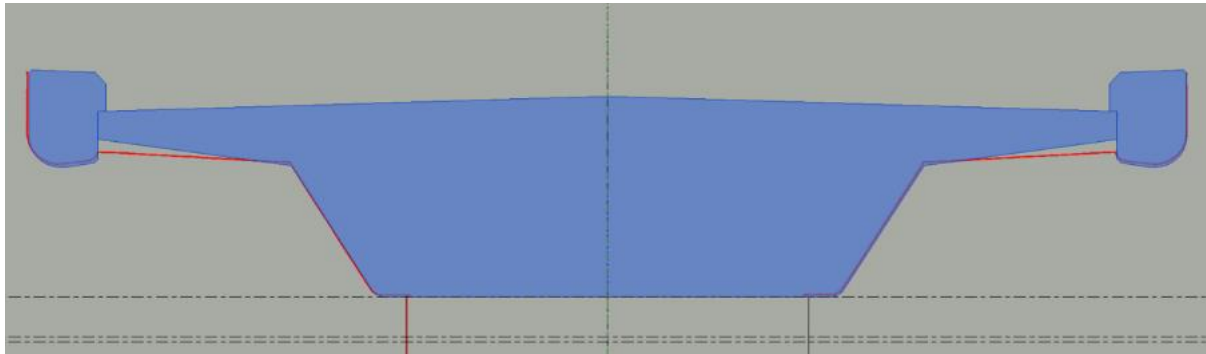
Figure 7–9 Section cut of the bridge profile. The red line is the point cloud, and the blue area is the cross-section of the Revit model.

The difference was significantly reduced after correcting the modeling error found in the *Revit* family, as shown in figure 7-10.
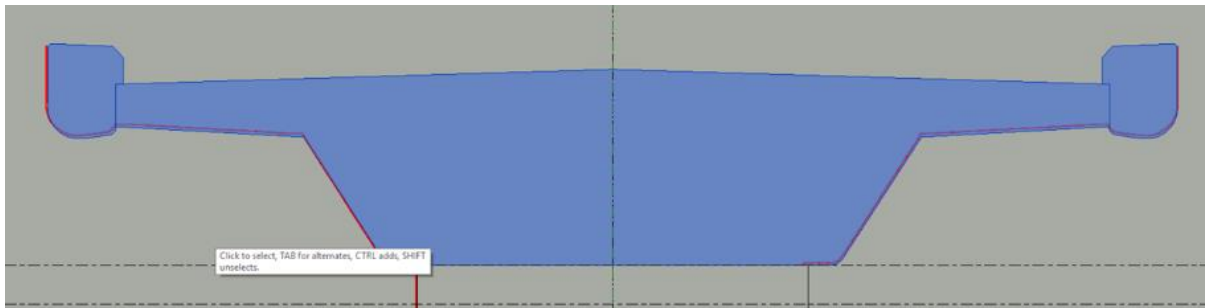
Figure 7–10 Correction of the model seen in a section cut. The red line is the point cloud, and the blue area is the cross-section of the Revit model.

7.5.3 The positioning of the model and point cloud

Manually moving the model to the point cloud is shown to be a complicated and challenging task in *Navisworks*. The *move* tools in *Navisworks* appears not to be accurate enough.

The positioning of three survey points and six survey points is a more systematic method for positioning the point cloud and model. However, from the test result is it shown that this method is challenging, and the placement of survey points is not accurate enough to achieve the same coordinates for the point cloud and the model.

Moving the host item to the as-built position shows that the geometry of the elements fits the point cloud.

7.5.4   Results from Verity analyses

Table 7-3 to Table 7-6 shows sections of the results of translation from the analyses done in *Verity*. The complete tables of results can be seen in appendix 18.

As shown in table 7-3, the element *Column Middle* was the primary target for manual placement and has the least total translation of 17mm. The analysis shows that the *Column Middle* is the element closest to the tolerance of 15mm. The remaining elements have a more extensive of total translation, and none of the elements passes the tolerance of 15mm.

Analysis 1	Maximum translation in mm						
Element Name	Total	Vertical	Horizontal	x-axis	y-axis	Long-axis	Cross-axis
Barrier North	58	-52	29	29	-6	2	58
Barrier South	72	-56	51	50	-10	-1	72
Column West	40	37	20	26	14	-37	20
Column East	23	9	22	-20	-9	-9	22
Column Middle	17	-1	17	-14	-10	1	17
Superstructure	56	-56	7	-7	4	-6	56
Abutment East	20	2	20	15	-15	-16	12
Abutment West	23	-2	23	-21	-9	-19	13

Table 7-3 Section of results from Analysis 1.

As shown in table 7-4, results from Analysis 2 show a sizeable total translation for every element and show that the point cloud fits inadequately to the model. It also shows that there is no relevance of the total translation to the placement of survey points within *ReCap*.

Analysis 2	Maximum translation in mm						
Element Name	Total	Vertical	Horizontal	x-axis	y-axis	Long-axis	Cross-axis
Barrier North	73	72	42	23	35	3	73
Barrier South	93	-91	43	23	36	-4	93
Column West	36	-3	36	31	-19	3	36
Column East	39	1	39	-5	-39	-1	39
Column Middle	59	-2	59	22	-55	2	59
Superstructure	81	-80	13	7	11	-14	80
Abutment East	37	6	36	29	-22	5	37
Abutment West	43	-4	43	42	9	17	39

Table 7-4 Section of results from Analysis 2.

As seen in table 7-5, results from Analysis 3 shows that the *Column East*, *Column West,* and *Abutment East* passes the user-defined tolerance of 15mm. The analysis gives greater relevance to the placement of the survey points. The results for *Abutment West* are undefined because *Verity* did not find relevant points for the elements and marked it as occluded. The remaining elements have a total translation that exceeds the defined tolerance and did not pass the analysis.

Analysis 3	Maximum translation in mm						
Element Name	Total	Vertical	Horizontal	x-axis	y-axis	Long-axis	Cross-axis
Barrier North	38	34	18	-8	-16	1	38
Barrier South	79	79	11	4	10	0	79
Column West	10	-1	24	22	10	2	24
Column East	13	0	13	-11	9	0	13
Column Middle	24	-2	24	22	10	2	24
Superstructure	55	53	16	-9	-14	17	52
Abutment East	8	2	7	-6	4	-1	8
Abutment West	-	-	-	-	-	-	-

Table 7-5 Section of results from Analysis 3.

Shown in table 7-6 shows that seven of the elements passes the analysis and shows that the geometry of the elements is built accordingly to the model. However, this does not indicate that the as-built elements are positioned correctly. The results for the *Abutment West* are undefined because in this analysis *Verity* did not find relevant points for the element.

Analysis 4	Maximum translation in mm						
Element Name	Total	Vertical	Horizontal	x-axis	y-axis	Long-axis	Cross-axis
Barrier North	12	1	12	6	10	0	12
Barrier South	8	-7	4	2	3	0	8
Column West	4	2	4	-2	4	-2	4
Column East	13	0	13	-11	8	0	13
Column Middle	7	-1	7	6	-2	1	7
Superstructure	13	11	11	5	9	-11	12
Abutment East	8	2	7	-6	4	-1	8
Abutment West	-	-	-	-	-	-	-

Table 7-6 Section of results from Analysis 4.

The four analyses show a difference in translation for most of the elements. One exception is the *Abutment East* that has the same translation in Analysis 3 and Analysis 4.

7.5.5 Discoveries from Verity

As for the software to automatically check the as-built point cloud to the as-designed model. *Verity* offers the tools and operations needed, and they work well together. The interface of *Verity* is straightforward and easy to learn

For a good visual representation in *Navisworks*, one should use a point cloud that contains a minimal amount of non-relevant information, as shown in figure 7-11.
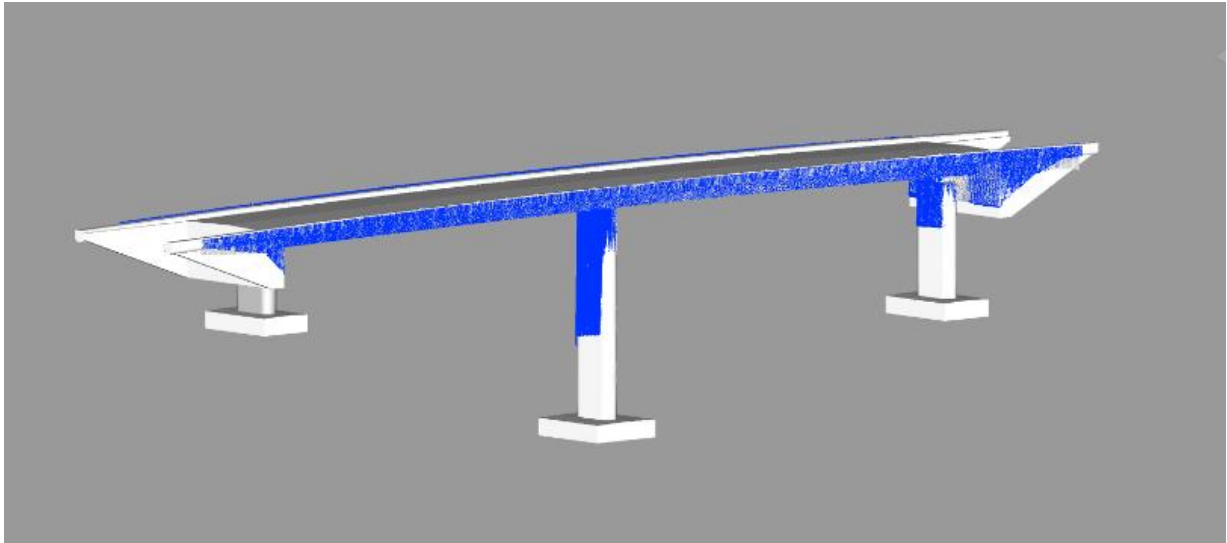
Figure 7–11 Model with the minimal amount of non-relevant information from the point cloud, marked as blue.

However, because of a bug in the current version *Verity 1.1.1 SP1*, *Verity* cannot run the analysis if points are deleted in *ReCap*. Therefore, it is necessary to import the complete point cloud in *Navisworks* leading to a lot of noise and unnecessary information from the point cloud in *Navisworks* shown in figure 7-12.
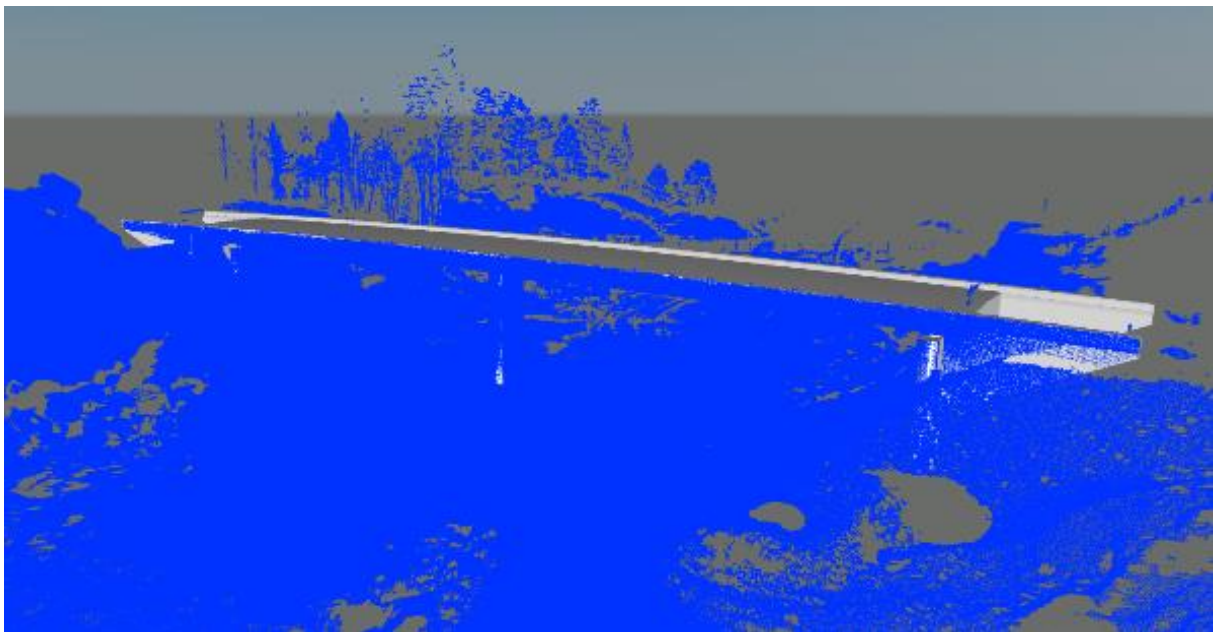
Figure 7–12 Model with unwanted information from the point cloud marked as blue.

This can make it more difficult to focus on the relevant elements in the model that are being analyzed, both for a user point of view and giving the recipient unnecessary information about the area around the elements. However, there are few to none problems with the analysis itself as *Verity* excludes points that are too far away from the element when running the analysis shown in figure 7-13.
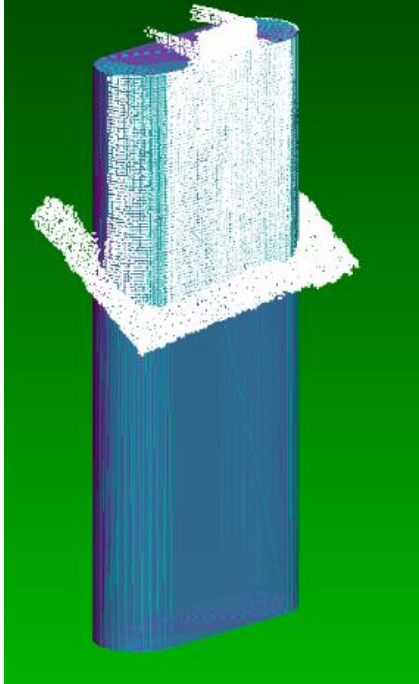
Figure 7–13 Points Verity found to include in the analysis marked as white.

Most of the copied elements that *Verity* creates to match the point cloud fits the point cloud acceptably as seen in Figur 7-14. This is an essential step for *Verity* to conclude if the construction is built according to the as-designed model.
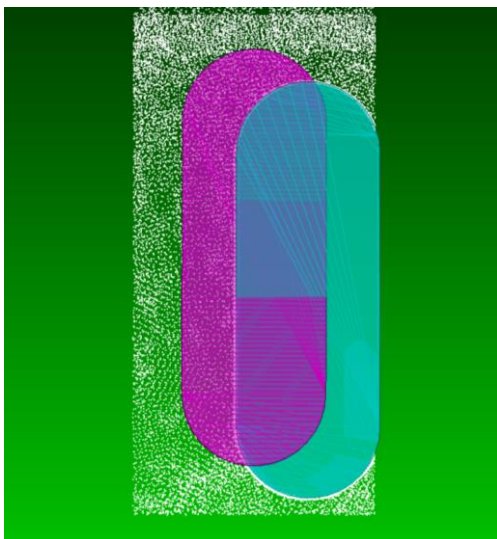
Figure 7–14 The relation of placement of the as-built element (displayed as blue) to the as-designed element (displayed as purple)

As seen in the same figure 7-14 *Verity* gives an excellent visualization to understand the relation in placement between the as-designed element to the as-built element.

With the heat map tools, *Verity* offers more understanding of the relations of placement between the as-built element and the as-designed element and provides a good understanding of the deviation between the as-built element and as-designed element shown in figure 7-15.
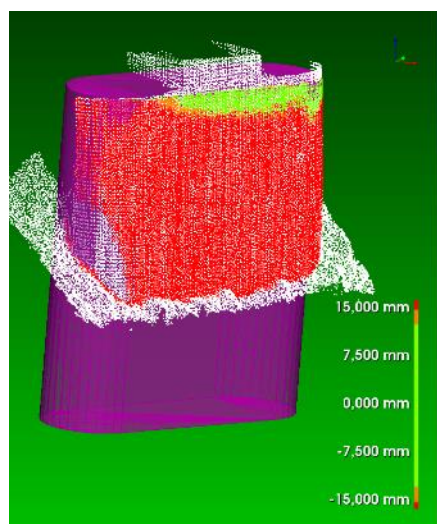
Figure 7–15 Heatmap to an as-designed element.

Verity also provides the understanding of how the software has fitted the as-built element to the point cloud and can be seen in figure 7-16.
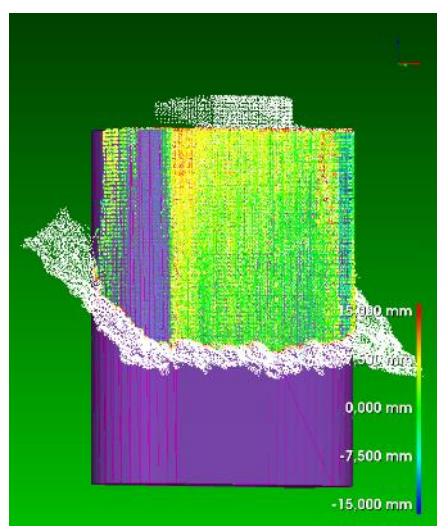
Figure 7–16 Heatmap to an as-built element

Along with the visualization and the heat map, *Verity* provides values for transformation and rotations of the designed element to the point cloud to give an understanding of the position of the element in XYZ coordinates. Values can be seen in the software, see figure 7-14, or as an HTML report, see appendix 14-17.

Item Description	Geometry Surface Area	Installation Status	Item Tolerance	Conformance To Tolerance	Reviewer	Review Status	Action Required	Notes	Total Translation	Vertical Translation (+/-)	Horizontal Translation
|| PolyFac...	73 196 734,511 mm²	Installed	15,000 mm	Out Of Tolerance		Not Reviewed			17,000 mm	-1,000 mm	17,000 mm
|| PolyFac...	23 190 498,891 mm²	Installed	15,000 mm	Out Of Tolerance		Not Reviewed			40,000 mm	37,000 mm	20,000 mm
|| PolyFac...	60 555 441,164 mm²	Installed	15,000 mm	Out Of Tolerance		Not Reviewed			20,000 mm	2,000 mm	20,000 mm
|| PolyFac...	479 999,981 mm²	Installed	15,000 mm	Out Of Tolerance		Not Reviewed			85,000 mm	29,000 mm	81,000 mm

Figure 7–17 Section of a table in Verity.

During the analysis*, Verity's* Algorithms tries to place the copied elements according to the point cloud. Most of the time the algorithms manage to place the copied elements acceptable. However, sometimes *Verity* misplaces the copied elements because of noise within the point cloud or missing

points. When this occurs, *Verity* offers tools to manually move the copied *element* to the point cloud and refit the copied elements. Therefore, *Verity* has the ability to fix the wrong placement from the algorithm without much time-consuming work. *Verity* found four elements that are misplaced to the point cloud and marked them as occluded. In figure 7-18 it is shown that the as-built element is a square box that is not placed in the correct position to the point cloud.
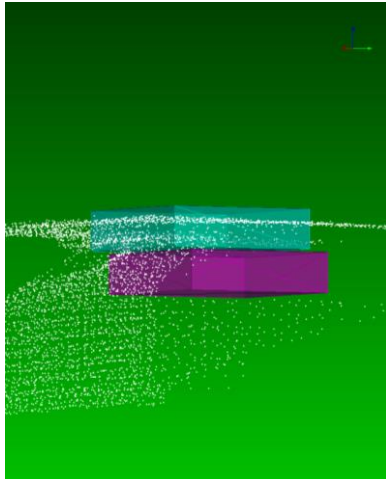
Figure 7–18 As-built element (displayed as blue) misplaced to its correct placement in the as-built point cloud.

The elements added to *Verity* can be marked as reviewed, and by who, there is also the possibility to add action required and notes. These tools are leading up to creating an automatically generated report from the analysis with enough information to be used to document the construction. The reports are straightforward and easy to read. Images of the element are implemented in the report to give a visual understanding of the position of the as-built element to the as-designed element. However, images are not always displayed acceptably. See example in figure 7-19. There seem to be no tools for adjusting the images of the report.
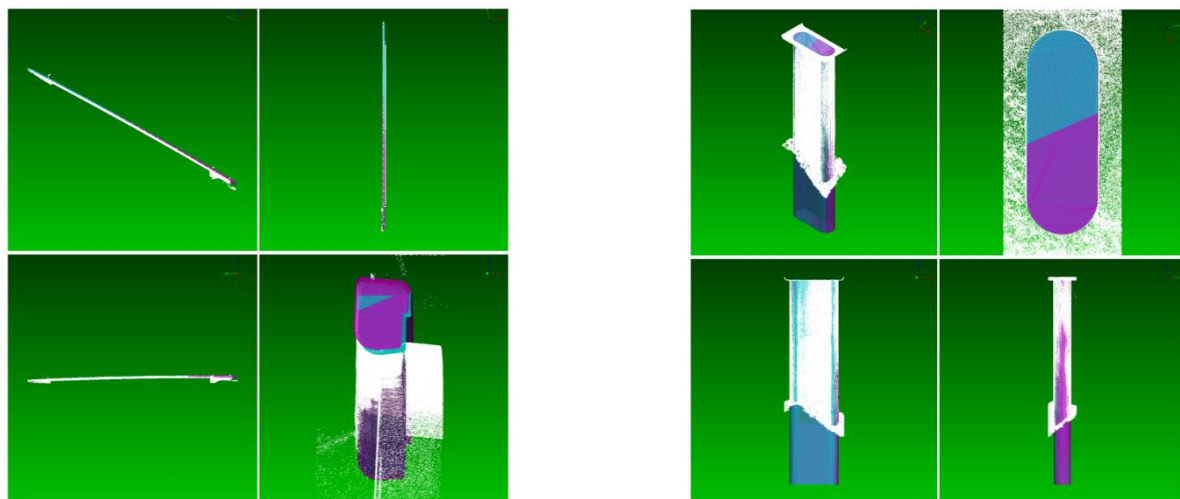
Figure 7–19 Examples of a poor (left) and good (right) image in the Verity report.

7.6 Updating the Navisworks model with the use of Verity

As a result, from the theory of *Verity user guide* in appendix 19, it is known that *Verity* can only update the *Navisworks* model to as built. Therefore, to update a model to as-built in another software must be done manually.

Data captured for translation, rotation, installation status and other values can be imported to each element in Navis work. *Verity* also color codes the elements after which installation status the element has. This is shown in figure 7-20.
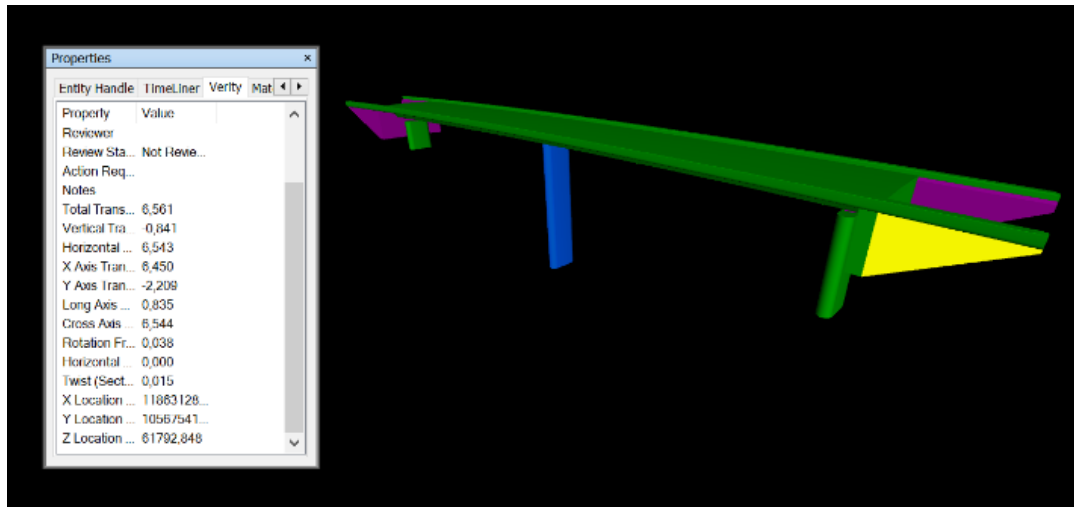
Figure 7–20 Color code of installation statuses implemented to the Navisworks model, with a table of parameters for the middle column displayed on the left side.

7.7 Certificate of conducted work

As a result, from interviews with the senior road director in *Nye Veier* and employees of *Kruse Smith*, theory from the contract and business model in chapter 3.3 and the results from *Verity*, it is indicated that the reports from *Verity* could be adequate to be used as a certificate of conducted work. The point cloud and model would, however, need credible and accurate global coordinates and also be agreed upon by the contracting client and the contractor during the contracting phase. [26, 56].

7.8 Update the Revit-model to as-built

To update the *Revit* model to as built the point cloud was linked into the *Revit* project, and the elements were manually moved to fit with the point cloud. Figure 7-21 and 7-22 are examples of how a before and after photo looks in *Revit*. While the point cloud was moved and not the elements, it should look the same as if the element was moved instead of the point cloud.
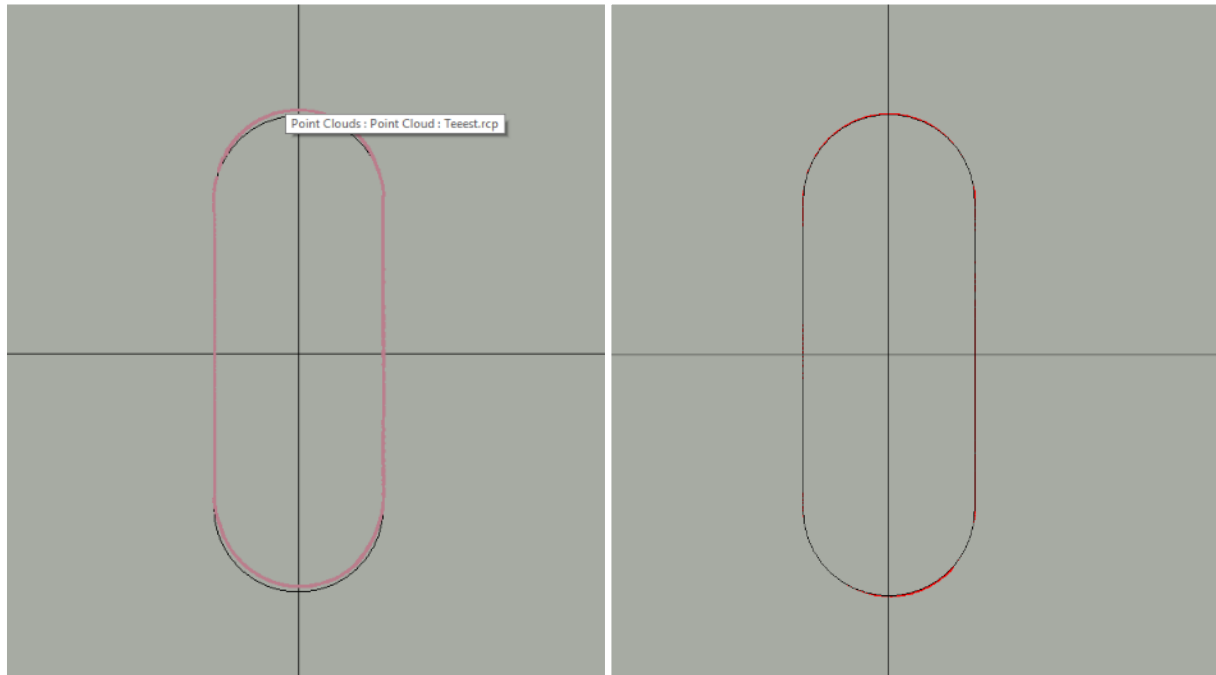
Figure 7–21 The left picture shows how a deviation between the point cloud (red line) deviates from the model (black line). The right picture shows how it looks after the point cloud was moved to a truer position.
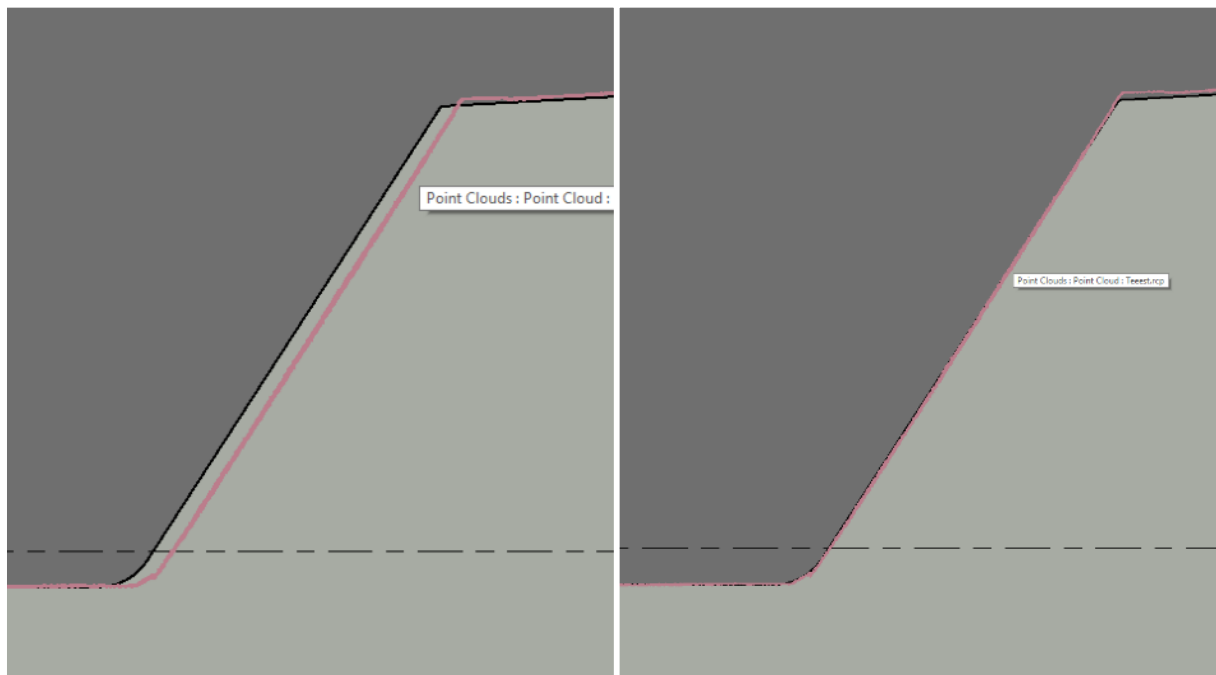
Figure 7–22 Another example of a before (left) and after (right) picture. The red line is the point cloud, and the black line is the model.

The curvature of the bridge proved to be too complicated to update to as-built because of the geometry. The model of the bridge follows a perfect circle with a radius of 1100 meters, and a scan of the bridge revealed that the bridge, as expected, did not follow a perfect circle. This shows that updating the model to as-built can be a challenging task and requires skilled operators. Figure 7-23 shows a section cut of the model along the length of the bridge and shows how the point cloud and model deviates at one of the end pillars.
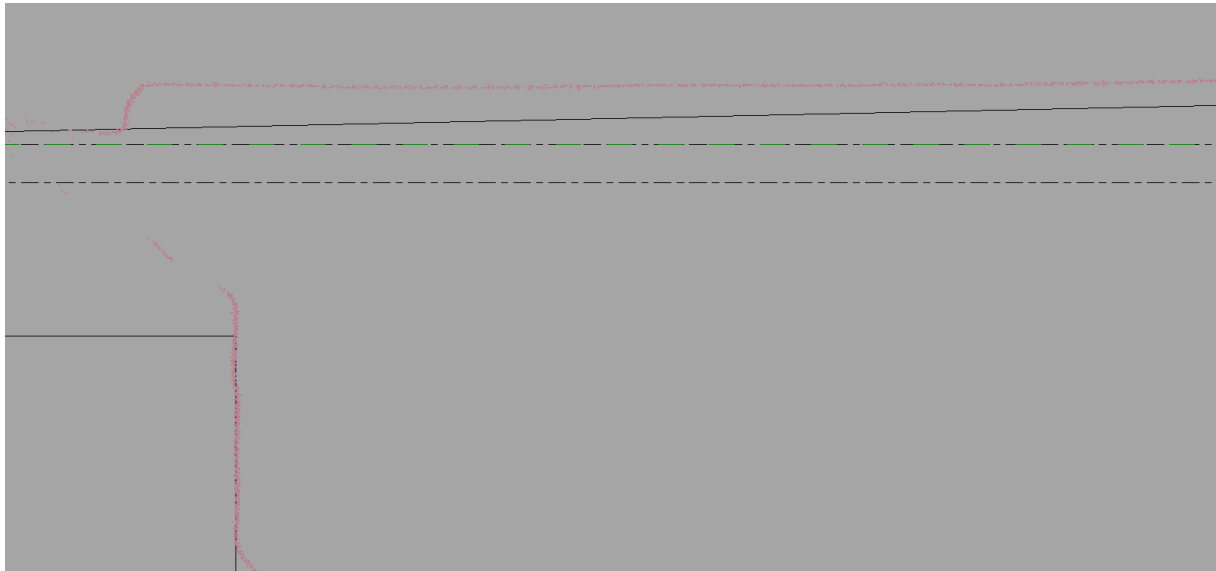
Figure 7–23 Example of the complex geometry of the bridge. The point cloud (red line) does not follow an idealized curve like the Revit model (black line) does.

There was made efforts to find tools to help automate the process of updating the *Revit* model, but none was found. While *Verity* can update a model, this is the coordination model and not the *Revit* model. The group did not manage to get the coordination model and *Revit* to cooperate, and thus the link between them was not tested.

7.9 Contract and enterprise

In interviews with professionals, the contract in a given construction project was said to be one of the primary factors in the use of BIM. During an interview, a BIM coordinator and a discipline leader in *Kruse Smith* argued that if BIM is not explicitly mentioned in the contract as part of the work description in chapter 3 of the NS 8415, BIM is not beneficial for the contractor. The contractor must get paid for the work in making and maintaining the BIM-model and associated tasks. See Appendix 9.

A senior director in *Nye Veier* with knowledge on BIM in the horizontal construction industry stated in an interview the group conducted that new contracts with *Nye Veier* will require a 3D model as part of the work description. Standards and manuals developed in Norway were, according to the director, excellent tools for a contracting client and the contractors in using BIM. He also noted that *Nye Veier* and multiple companies, such as *BaneNor and Statens Vegvesen*, were actively working on new standards which could ease the use of BIM. *Nye Veier* requires specific tasks of the contractor, such as deviation documentation, but not the specific tools, such as *Byggeweb Capture*, in their contracts. Further, he stated that there are intensives for innovation in the contracts;

Implementation of new software solutions or other means of efficiency increasing can be rewarded through increased earnings, see Appendix 10 and Appendix 24, [73].

The sub-contractor Kruse Smith in the project case E18 Tvedestrand-Arendal gave access to their contract with the general contractor, see Appendix 11, [56]. The discussion chapter will contain excerpts from this NS 8415-based contract which will serve as examples deemed relevant to the research question regarding reporting.

7.10 Reporting

Table 7-7 shows the function evaluation of *Dalux Field*[38]*, Byggeweb Capture*[36] and *Avvik.com*[74]. *Dalux Field* has the better evaluation score, even though it shares several qualities with *Byggeweb Capture.* The most important differences between the two are the 3D model visualization and the file format importation and exportation. *Avvik.com* scored poorly in comparison to the other software choices.

Features	Dalux Field	Byggeweb Capture	Avvik.com
Import ifc-files	✓	✗	✗
Export report in BCF files	✓	✗	✗
Export report in excel	✓	✓	✓
Export report in xml-format	✓	✓	✓
Export report in pdf-format with drawing overview	✓	✗	✗
Organize hierarchy/enterprise	✓	✓	✗
Use in field	✓	✓	✓
Use in office	✓	✓	✓
Use in the construction phase	✓	✓	✓
Use in facility management phase	✓	✓	✓
Include all ranks	✓	✓	✓
3D-view	✓	✗	✗
2D-view	✓	✓	✗
Handle different professions	✓	✓	✓
User-friendly	✓	✓	✓
Handle 4D	✗	✗	✗
Task history	✓	✓	✓
Photo documentation	✓	✓	✓
Video documentation	✗	✓	✗
Locate task in model	✓	✗	✗
Locate task on drawing	✓	✓	✗
Task database	✓	✓	✓
Smartphone/tablet application	✓	✓	✓
Tasks can have GPS data	✓	✓	✗

Checklist	✓	✓	✗
Handle HSE	✓	✓	✓
Handle quality deviation	✓	✓	✓
Offline use	✓	✓	✗

Table 7-7 Function overview for Dalux Field, Byggeweb Capture, and Avvik.com.

Once a task/report has been established, it will appear on the floorplan (see figure 7-24). The coordinates in which these color-coded points are situated are the spot where the report was created, and not the element that the report was created for. In short, it is not the element that is given information, but rather a coordinate. This can be problematic.
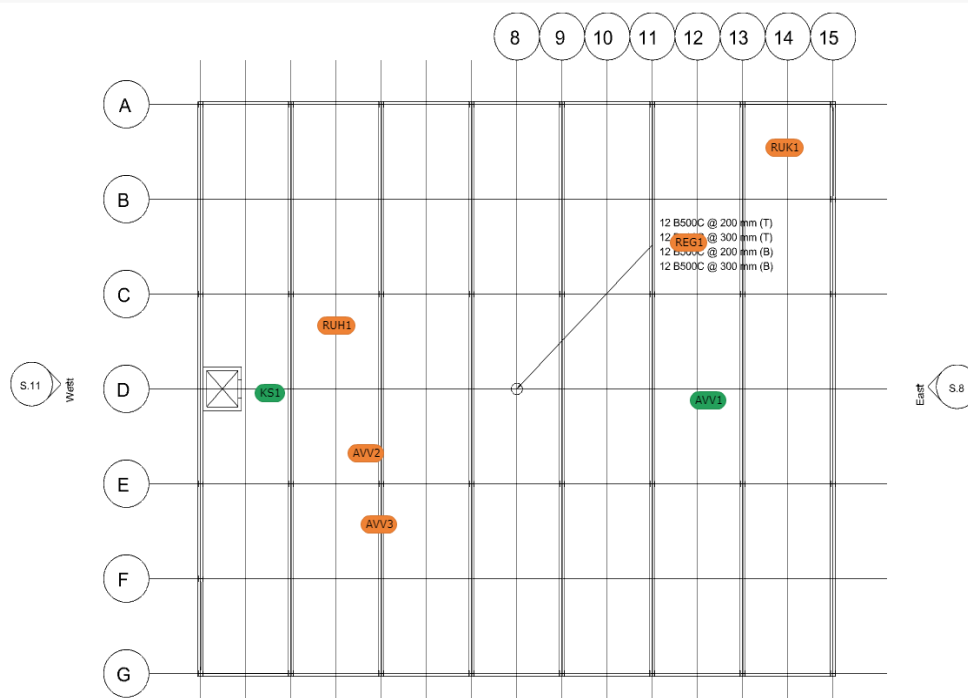
Figure 7–24 Example of tasks shown on floor plan. Green dots are completed tasks while orange dots are unfinished tasks. The location of the dots is the same as where they were created, and not which element they are connected to.

Dalux Field is a program that works well for reporting on a construction site. The report is precise and informative in addition to its low user interface. Additionally, *Dalux Field* reports are generated in a model environment and can export information through BCF-format to any BCF-compatible software the recipient may be using, for example, *Revit*. This will transfer the report information back to the BIM model. The organization of enterprises within the program allows the project manager to keep an overview of the different professional groups, as well as the internal assignment ranks in each group. This also contributes to the simplicity of selecting an appropriate receiver for a deviation report. The use of *Dalux* has a span from office to field and can be used during both the construction phase and the facility management phase.

Dalux Field allows tasks to be created on drawings unaccompanied by a model, meaning that a "floorplan" of a road, or in this case a bridge, can be imported and used for deviation reporting. This

is not model-based in any way but does allow some application of *Dalux Field* in the horizontal construction industry. As it is only a drawing, the reports will not carry element information from a BIM model; it will not be parameterized. This use of *Dalux* Field seems quite similar to *Byggeweb Capture*. The positioning for the task/report has global coordinates, which means that the coordinates are accurate both on the drawing and in the real world. This information is important for discipline leaders. Figure 7-25 displays a plan drawing of *Mørland* bridge that has the potential for the earlier mentioned use.
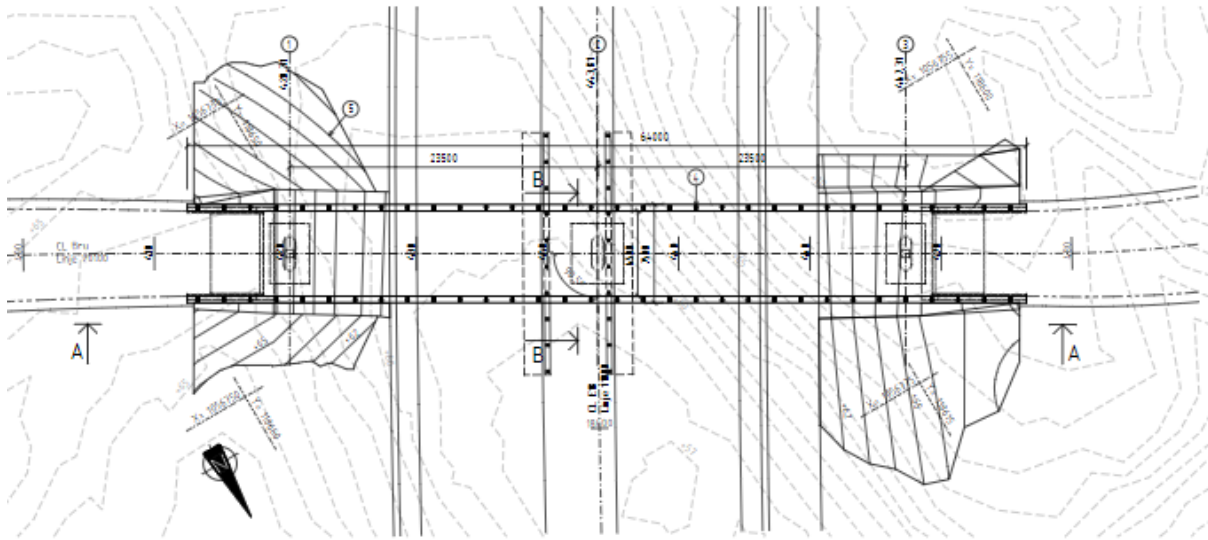
Figure 7–25 Plan drawing of Mørland bridge. This drawing alone could potentially be used in Dalux Field for deviation control, but would not capitalize on the model-based functions offered by the software.

Dalux Field does not yet handle 4D sequencing data. Progress management is required to be handled in an alternative software. Drawings are required for the smartphone and tablet application to show the model in the embedded viewer. This means the model itself is not sufficient for the software to work as intended.

Regarding *Kruse Smith*'s work on the project case E18 *Arendal-Tvedestrand* as contractors for the bridges, *Dalux Field* would first be useful only after *AF Gruppen* provides an IFC-model and detail drawings in for example PDF-format or DWG-format. In later projects, however, it would be beneficial to the contractor if they could participate in the projecting phase, and contribute to the BIM-model. For example, the use of another software to split the bridge into several cast stage-elements before the exporting as an IFC-model to *Dalux Field* would benefit information flow in the issue management.

Another issue with the use of *Dalux Field* is the absence of items such as cranes, formwork, scaffoldings and other elements essential to a construction site. A significant amount of deviation originate from these elements, but they are however generally excluded from a traditional BIM. A contracting client would perhaps involve an architect in a project first, who in the best-case scenario works in *Revit*. Then perhaps, a consulting engineer would begin on the structural BIM. Only very late, if ever, would the project manager plan the procurement of for example scaffolding and the corresponding logistics. The project manager would then need to implement scaffolding and such in cooperation with the BIM manager into the BIM-model. Only then would *Dalux Field* be fully utilized.

Dalux Field cannot be utilized to its full potential for use on bridges. The major components of a bridge consist of large amounts of concrete cast into large elements. When marking such a component in *Dalux Field* on a smartphone/tablet, the entire element will be highlighted. This removes the possibility to create a task on a specific, and perhaps small, part of a larger element. This is a result of *Dalux Field* initially being designed for use on buildings, which has a significantly higher number of components, and not other types of constructions such as bridges and roads. Note that the figures below, figure 7-26 and figure 7-27, displays models that have very low detailing. However, the principle of large elements still applies.

Figure 7–26 An element (abutment) marked in Dalux Field. To mark smaller parts of a bigger component, the component would have to be modeled as several smaller elements or somehow cut into smaller parts. This cannot be done in Dalux Field.

Figure 7–27 An element on the bridge marked in Dalux Field. It highlights the entire component, resulting in a much less accurate report, element and location-wise.

The report/task itself has been evaluated. The report contains much information on one sheet, but this does not mean it is disorganized. Which type of report it is, who the sender is, the location of the task, date, and more. are quite easy to read off the sheet. Regarding quality on the receiving end, the fact that the possibility to enter the model exists makes it easier to scout the surroundings for a better picture of the situation. The receiver also has the option to add information if s/he finds it necessary. Figure 7-28 displays the layout of a report and substantiates this. These types of reports containing information about the date, responsibility, sender, and receiver can be used as evidence in case of conflicts between the different parties.

Figure 7–28 Example of a deviation report in Dalux Field. It contains information necessary for, for example, a discipline leader or a project manager. The location for the task is clearly visible on the floorplan and is one of the improvements from Avvik.com.

7.11   Dalux Field Test

The following procedure is done with the prerequisite that the model, along with the corresponding drawings already has been imported and treated in *Dalux Field*, and that the different enterprises for the project have been established. An example of the enterprise overview is shown in figure 7-29.
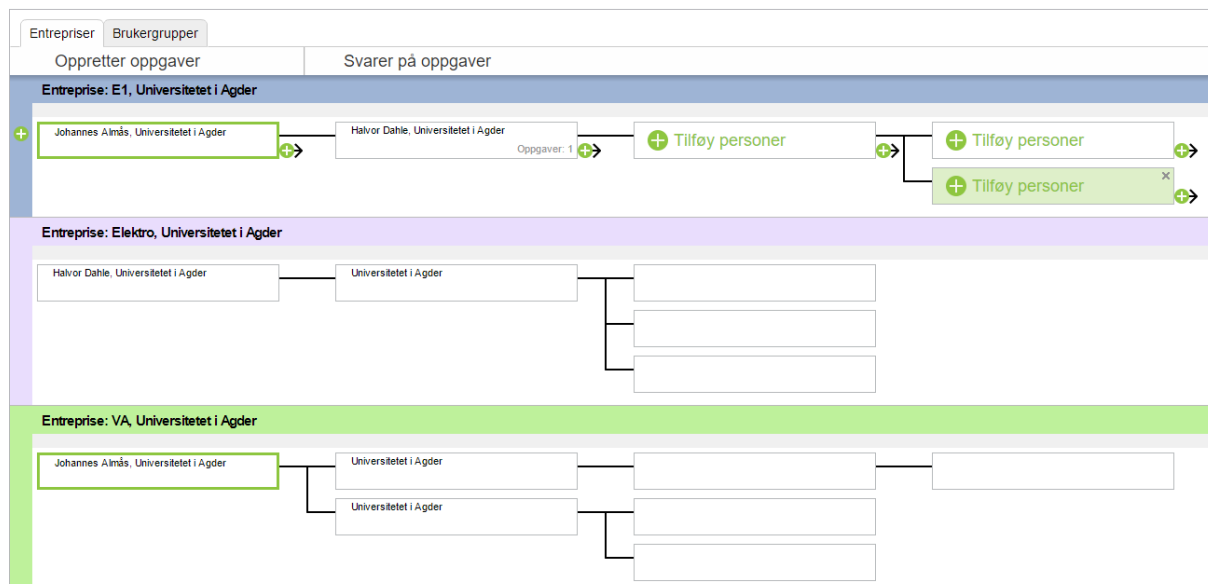
Figure 7–29 Example of an enterprise overview. This organization tree decides who is responsible for delegating tasks and to whom.

In the *Dalux Field* smartphone application, choose the designated floorplan for your current position, as figure 7-30 displays.

Figure 7–30 List of the different floorplans that have been imported and attached to the model.

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Once the floorplan has been selected, there are now two viewing options; Plan view or 3D view. By tapping somewhere on the floorplan drawing, a green dot will appear along with an option to go into the 3D viewer or create a task. The smartphone/tablet screen will look like figure 7-31.
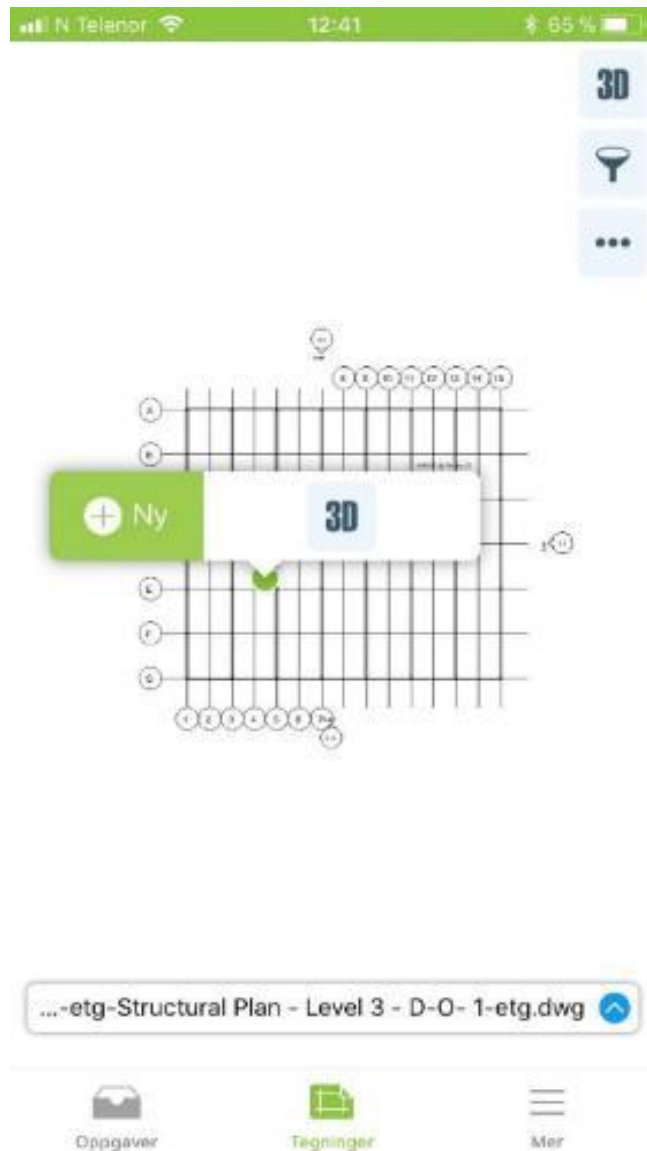
Figure 7–31 Option to either create an assignment or enter the 3D viewer.

Enter 3D view. The viewer will now show the construction from a first-person view. By clicking any element in the construction, four clickable buttons will appear as shown in figure 7-32. The scissors icon will provide the option to drag the visible plane of the building as desired. The icon that shows a box with a line across it is used to hide the selected element. The information-icon can be clicked to

show the specific properties of the element. Lastly, the "*+New*"-icon is the option in which a new task can be created.
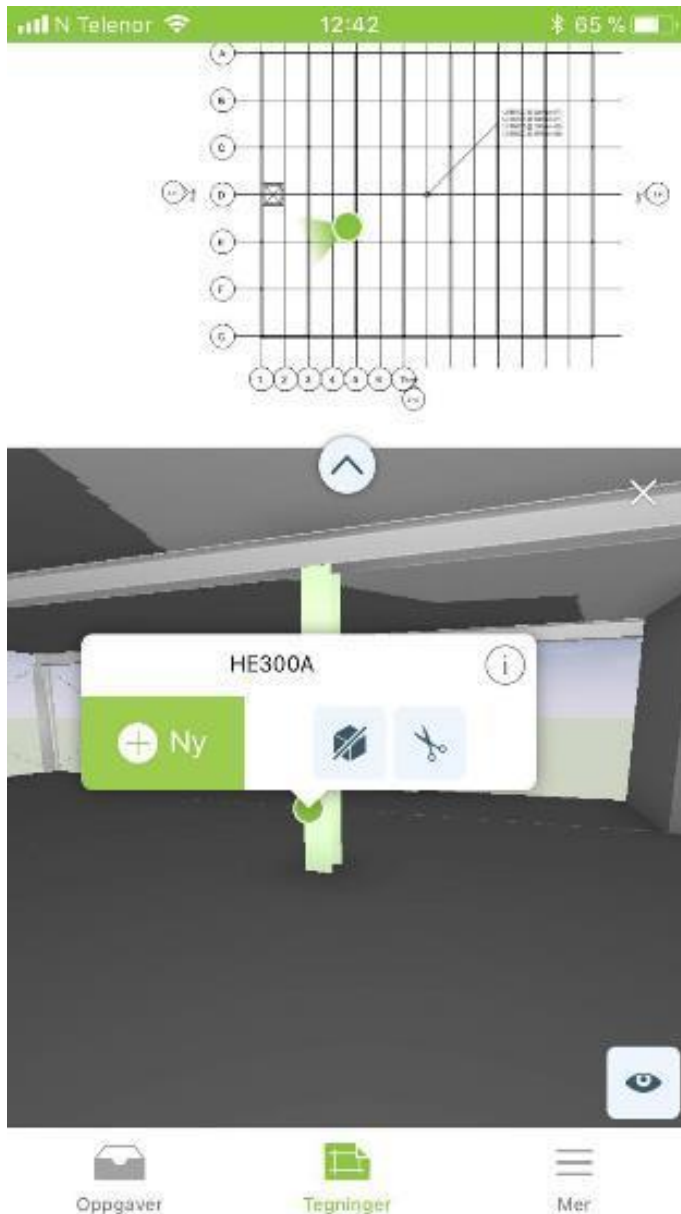
Figure 7–32 Options that are given when clicking an element within the 3D-viewer.

Click the "+New"-icon, and a new window will open. There are now seven different options for seven different types of tasks/reports. Click "Deviation" to create a report on deviation. The report sheet will appear as displayed in 7-33. A photo can be attached to clarify the issue and ease the job for the respective respondent.

Figure 7–33 An empty report sheet for reporting deviation.

The task can be assigned to whoever, according to the enterprise sheet, is responsible for approving or completing the tasks. An example can be seen in figure 7-34.
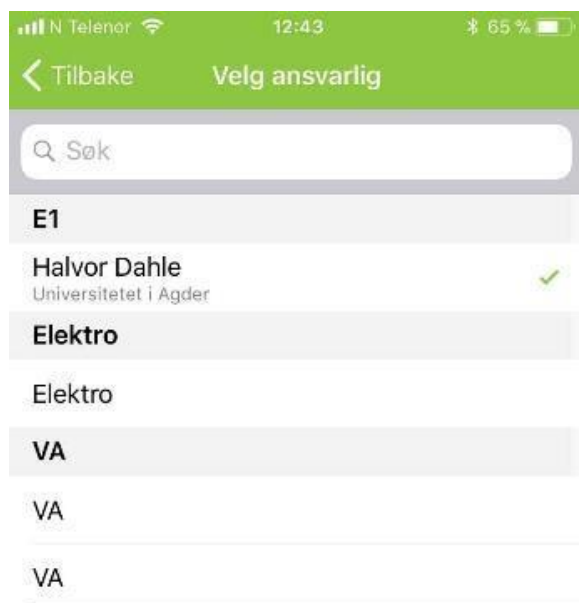
Figure 7–34 Assign tasks

Once a report or assignment has been registered, it will appear in an overview along with all tasks. To decide whether a task has been processed, there is a color code system as well as a file system to arrange tasks according to their respective state. See figure 7-35 below.

Figure 7–35 Tasks are arranged by colors, where each color represents the status.

A task can now be reviewed for approval. In some cases, a task might go back and forth in the enterprise chain before it is marked as complete. A registered report can be viewed by clicking on a task and choose "show." This will open a window, as in figure 7-36, with all the information that was filled in earlier, along with the name of the sender.

Figure 7–36 The registered report on the receiver's part. If a picture is attached, it will also be part of the report.

8. Discussion

8.1 Survey

The data was never to be purely quantitively analyzed, it was instead meant to provide a confirmation or denial of the assumptions towards the attitude regarding BIM, Lean, and reporting in *Kruse Smith*, as seen in Appendix 5. Even so, the data from the focus group from the construction industry will not be equally evaluated due to its low distribution and response rate. The complete data overview is shown in cohesion to follow the primary way of table 7-1 and Appendix 6 and Appendix 7.

The survey showed that most of the respondents considered their digital abilities medium to very good. However, their evaluation is subjective, as it depends what their abilities are compared against. The fault was in the question phrasing, as the answer does not provide what the ability was compared to. One could argue that one who deems their knowledge to be good on a given subject is more receptive to learn even more, and might even enjoy working with the subject. This would, however, be ungrounded speculations and presumptions. Thus, the question data was not used in any further work.

When it came to the use of digital solutions in their workplace, everyone answered either to a medium or large degree. However, the respondents' way of presenting their work showed that few did so using BIM models as documentation and result. This might highlight the fact that BIM as a method may not be as implemented in the daily workflow as one could presume.

Question number three ("*How long have you been work active in the horizontal construction industry?*") was meant to give data regarding the presumption that older professionals were less prone to agree to new digital solutions. However, the analysis could not say if it was true or not, based on the data received.

Question number five ("*To what degree is digital solutions used in your firm*?") was meant to provide data on how *Kruse Smith* compares with the rest of the construction industry. The survey was however not distributed to any comparable contractors, and the question of *Kruse Smith* being better or worse than the average when discussing digital solutions could not be concluded. The survey distributed to the construction industry, in general, was primarily distributed to consulting engineering firms, which was revealed in question two. Also, as question five was meant to indicate the use of BIM or other comparable software solutions, it could be misinterpreted to mean any digital tool. Thus, the question was not the basis for any conclusions.

Question number six ("*in what format is your work presented*?") showed that *Kruse Smith* had a smaller degree of BIM in their work. However, *Kruse Smith* is a contractor. The survey which was supposed to represent the construction industry, however, was answered mainly by consulting engineers. Contractors in an NS 8405-contract generally does not stand responsible for the projecting other than their tender of a given construction project, and indeed not if the contractor, in fact, is a sub-contractor under a general contractor in an NS 8415-contract. During the interview with a senior director in *Nye Veier,* it was stated that sub-contractors in the E18 project are not required to deliver BIM models [73]. As *Kruse Smith* is a sub-contractor in the E18 construction project, and that the survey meant to represent the construction industry was mainly answered by consulting engineers, one cannot compare them based on the question phrased as it is in the survey.

Question seven ("*In your opinion, do you know what BIM is*"?) activated the BIM related questions if answered positively, and was initially meant as a filter on the following BIM related questions so that respondents with little knowledge on BIM did not meddle with the BIM survey data. The question phrasing was, however, deemed insufficient during the analysis phase; One could not assess the respondent's knowledge on BIM-based solely on the answer given on question seven.

The data from question eight ("*To what extent are you satisfied with the use of BIM compared to construction projects without BIM?*") in *Kruse Smith*'s survey provided data that has to be interpreted, as a significant amount of the respondents answered neutrally. It was therefore decided that as it could be concluded in either direction, it was best to nullify the question altogether.

Data from question nine ("*To what extent is BIM used in your workplace?*") aligned well with statements from the interview with a senior director in *Nye Veier* [73], and what was found in the contract between *Af Gruppen* and *Kruse Smith,* regarding the use of BIM in the construction industry; skilled workers (for example carpenters), sub-contractors and general contractors use less BIM than consulting engineers. The data from question ten ("*to what extent have you been offered lessons in BIM?*") could be interpreted mostly the same way as for question nine.

Question eleven ("*To what degree would you say today's system for schedule reporting works?*") ,and question twelve ("*To what degree would you say today's system for deviation reporting works?*") showed that *Kruse Smith* was quite satisfied with today's system while the construction industry, in general, was more dissatisfied. At first, the data was interpreted as such: *Kruse Smith*, representing the contractors, was satisfied with the traditional system of reporting, while the other group, being mainly consulting engineers, were dissatisfied. This first interpretation was a confirmation of a presumption noted in Appendix 5, that project managers and consulting engineers are more prone to digitalization and new software solutions. However, it was later discovered that *Kruse Smith* was already using software solutions such as *Avvik.com* and *Byggeweb Capture*. Meaning that when they answered the survey, it was these software solutions they were evaluating positively, not the traditional system. Furthermore, *Kruse Smith* responded just as optimistic on question thirteen ("*To what degree do you think Lean Construction/Involving Planning would be of help to your workplace?*") and question fourteen ("*To what extent is Lean Construction affecting your work today?*") as the other group responded. Leading to the windup that if anything, *Kruse Smith* is at least not worse off than the construction industry in general.

There are many possibilities in BIM that are being discussed and talked about. The problem, however, is that many of the BIM solutions people discuss are at least a few years in the future. While it is important to think ahead about possible future developments in the business, it is also essential to embrace the solutions that are presented today. The road to level 3 BIM is long and cannot be reached in a day. The necessity to also see what is possible today with less effort was emphasized by both the external supervisor, who is responsible for innovation among other things as a technical director in *Kruse Smith,* and a senior director in *Nye Veier* who also is involved in innovation.

8.2 Interviews

In-person interviews are less prone to misunderstanding, as one can quickly follow up uncertainties and avoid misunderstandings that could arise from the misinterpretation of questions in an e-mail for example. Interviewees are also usually more likely to diverge onto potentially relevant subjects than

in an interview by e-mail or phone [4]. The Snowball-effect of getting new interview objects from another interview object can be translated to the effect of getting new information and subject threads during an interview about another subject. For example, the subject of 3D scanning was brought up during an interview about BIM but came to have great effects on the thesis.

It is somewhat problematic to select interviewees by their in-depth knowledge, as the evaluation of their supposed knowledge is done by the interviewer who as a basis does not yet have said knowledge. Interviewees were therefore selected primarily because of their work-position, and their connection to the project case, for example, BIM coordinators, senior directors, and discipline leaders. Choosing interviewees based on their interest or competence within a subject makes the interview data prone to being subjective. One does not necessarily get the representative opinion of the construction industry regarding BIM when interviewing BIM coordinators. This was considered when analyzing the interviews and cross-checked with literature studies.

As the interviews were qualitative, and the interviewees had different disciplines, only some of the answers could be compared, despite being based on the same interview guide. The interviewee's self-interests in a product or vaunting of their company could affect their answers, or to refrain certain aspects that would change the overall impression. To counter-act this discrepancy, the group conducted preliminary research to be somewhat objectively critical and rational in analyzing the interview data. Control questions, founded on the preliminary research on uncertain aspects of the subject, helped illuminate shortcomings in the interviewee's presentation of for example the software solution they represented. Also, the general knowledge in the group of the potential subjective responses aided in more correctly analyzing the interview data. Improvisation was mainly done where the interviewee had their subject strengths, which made interview data comparison complicated beyond the opening questions in the interview guide.

Although all subjects that came up during the interviews were asked upon, and written down and discussed in the group afterward, not everything ended up being directly useful or relevant to the project. As the research was quite expansive, that some information could not be followed up was clear from the beginning. However, the expansive research would ensure that the relatively few informants provided enough data to base further literature studies upon.

There were intentions to interview construction workers early in the research phase to collect their experiences and attitudes towards reporting and Field Management software. The same workers were then to be presented with the results of the thesis, and their opinions are regarded when concluding this thesis. However, after discovering early in the semester that a fellow student wrote their master's thesis on this particular subject, it was decided that this group's thesis was to have a different focus. Additionally, the project case situation implied the same perspective as the external supervisor. Thus, the group's thesis approached the subject of reporting more from a manager's perspective.

A weakness in the method when it comes to the reporting part of the project is that the group got the license for *Dalux Field*, but did not have access to *Avvik.com* and *Byggeweb Capture*. Consequently, while tests were conducted in *Dalux Field*, the information regarding *Avvik.com* and Capture had to primarily come from interviews, conversations, online websites and videos and literature studies. This may have negatively affected the credibility of the comparison as the group's personal experience may have fallen in *Dalux*'s favor. Also, it was learned from the interviews that the solutions from *Avvik.com* and Capture had several flaws that the BIM Coordinator and Discipline

Manager disliked. As a result, the opinion was received that today's solutions for reporting were insufficient. Even though this might have been true, it would still weaken the objectivity of the different software which in turn could result in subconsciously wanting to prove that *Dalux Field* is the best solution.

8.3 Processing the point cloud

Processing the point clouds took a significant amount of time, where the majority was spent waiting for the software to finish its task. Since most of the time the hardware was not utilized, there does not seem to be a way to significantly reduce the wait time, by using more powerful hardware. A more efficient software appears to be the only way to reduce the calculation time significantly.

The long compute times is an issue for *Smart Inspection* as well, and they were interested in any ideas on how to increase efficiency here. This is also something that *ClearEdge3D* sees as an issue, and their advice is to have computers processing twenty-four seven on larger projects according to their director of sales[52, 72].

While the reason for the long processing times could be affected by the group's inexperience, or from not having more powerful hardware, it is in line with the experience of more competent operators and should not invalidate the results.

8.4 Documenting the bridge

The workflow mentioned in results chapter "documenting the bridge" is a recommendation the group has created with the experience from the studied theory and experience from the different software used to document the bridge. However, because of the time left this workflow has not been tested in the recommended workflow, but every step is tested for itself.

According to *ClearEdge3D*, *Verity* is the first software on the market that offers a solution on how to automate the deviation control between a model and the point cloud and updating the model from as designed to as built. *ClearEdge3D* claims that they have a two years advantage over the competitors and are expecting competitors in the future. Based on this and on how competition promotes innovation, there is natural to expect development in this area in the following years. Depending on the price, this will increase the viability of BIM-based deviation control.

The results show that *Verity* simplifies the process of using 3D-scanning for model-based documentation. *Verity* makes the documentation process more efficient with an automated function for deviation control and for creating reports. However, *Verity* is not essential for the model based documentation as it is possible to do visual checks with *Revit*. However, *Verity* is still highly recommended as the software makes the documentation process more time efficient with fewer chances for human-made errors.

The more complex a project is, the higher the potential yield of using *Verity* is. A bridge is a relatively simple construction because it only consists of a few but large elements. While this by no means makes a bridge easy to construct or document, it does make it easier for humans to do manual checks. It is evident that checking four or ten elements, for example, a bridge, is more straightforward than checking the several thousand elements one finds in more complex structures like an office or a hospital.

Because of reasons outside the groups control the bridge was not scanned before 22 March, which was late in the project. This negatively affected the work on point clouds, as many processes were depending on the point cloud, and could not start before the bridge was scanned, and, as such limited, the amount of productive time and how much work could be done. This is something that ideally would be improved in another project. While this was a setback for the project, it should not drastically alter the conclusion.

8.4.1 Scanning the bridge

No significant issues arose while scanning the bridge, and the process left a positive impression. While six spheres were used as points for coordinating the different scans, a higher accuracy could have been achieved if more spheres were used.

8.4.2 Visual check with Revit

Overlapping the model and the point cloud appears to be an acceptable way of doing detail inspection, but would not be feasible as the only method for deviation control, especially on large or complex projects. However, this could change if used in conjunction with a heat map analysis, as a study found significant time savings and increased accuracy over the manual method. However, because the group could not find a way to do heat map analysis without *PointSense* and only had access to *PointSense* for a limited time, this could not be tested.

8.4.3 Method for positioning the model and point cloud

The method for manually positioning the model and the point cloud is not ideal as it is exposed to faults from the user, and it reduces the credibility of the data. Because in every step of the positioning proses it is up to the user's subjectivity to determine the best fit for the position of the model to the point cloud. It is possible to have a construction that is built precisely as designed with the only deviation being the placement, and this could be hidden if the position of the point cloud and model is manually placed.

The tools used in *Navisworks* to navigate the model is not easy to use for exact placement. However, there underlay the possibility that with more experience with *Navisworks* the usage of the movement tool may be improved. The difficultness for the positioning also depends on the complexity of the model. The model used in the analysis consists of many different angles and curved lines with a small number of familiar corners, thus making the model complex. Therefore, this method of manually positioning the model and the point cloud gives less credibility to the analysis results and there is not enough data to conclude if the elements are out of tolerance because of faults in the constructing process, or from faults when positioning the model and point cloud in *Navisworks*.

The method used for the analysis of three survey points and six survey points was tested to see if it could give more credibility to the results from the analyses. This method relays less on the user's subjectivity because it tries to achieve the same coordinates for the model and point cloud before importing them to *Navisworks*. However, from the analysis results, it is shown that applying three survey points, and six survey points to the point cloud give the two point clouds almost similar coordinates for the chosen points, but a slight change in orientation. The weakness of this method seems to be when extracting the coordinates from points in *Navisworks* and manually place the survey points and entering their coordinates into *ReCap*. The reason for this weakness may be that

there a too few recognizable points in *Navisworks* and *ReCap* that are in a decent range to the scanner, thus making the placement of survey points in *ReCap* more difficult. Therefore, this method of positioning the model and the point cloud also gives less credibility to the analysis result and there is not enough data to conclude if the elements are out of tolerance because of faults in the constructing proses or faults form the positioning in *Navisworks*.

The method used for moving elements to the as-built positions gives no credibility to if the as-built elements are position correctly in placement and orientation to the as-designed. However, it gives credibility to tell that the elements fit the point cloud in *elements* and shape, and to tell that the elements are constructed accordingly to the as-designed model.

To achieve more credible results, both the model and point cloud should have their exact global coordinates before being imported into *Navisworks*. This gives the credibility for that the model is modeled with the global coordinates of the real-world positioning and that the point cloud has the exact global coordinates of the as-built position. With these parameters, the analysis could tell more than if just the geometry of the elements is adequate. It gives the credibility to tell that if the point cloud does not fit the model, the construction is not built correctly after the model. However, there is still a possibility for user errors when inserting the coordinates to both model and point cloud. Other reasons for an inadequate analysis could be a fault when registering the point cloud, or that the model was not updated with the latest changes in the project. Unfortunately, because of the resources, we had available we were not able to register coordinates for survey points to get the exact position for the as-built bridge. Therefore we were not able to run the analysis with the credibility that can be achieved in *Verity*.

Aspects of the result show that *Verity* can be used to document a construction. Despite none of the methods tested for positioning the point cloud and model seems to give desirable results to conclude that *Verity* can be used as a documentation software. The results show that with a relative good placement of the model and point cloud the main elements for the positioning pass the analysis and it is possible to check if the geometry of the elements is built correctly. Therefore, With global coordination for the model and point cloud the deviation control, *Verity* automatically conducts could document that a construction is built as designed.

Despite only having tested the geometry and the relative location of the elements, the result should still be valid enough to conclude how 3D scanning can be done if the model and point cloud had global coordinates.

8.4.4   Verity analyses

The results shown in table 8-1 are the total translation of the elements for the four analyses and are presented in the discussion chapter to discuss the results of the analyses.

Total translation (mm)	Barrier North	Barrier South	Column West	Column East	Column Middle	Superstructure	Abutment East	Abutment West
Analysis 1	58	72	40	23	17	56	20	23
Analysis 2	73	93	36	39	59	81	37	43
Analysis 3	38	79	10	13	24	55	8	-
Analysis 4	12	8	4	13	7	13	8	-

Table 8-1 Total translation of the elements analyzed with Verity.

From the comparison of the elements in the different analyses seen in appendix 18, There are found no relations between analysis 1 and analysis 2. However, in analysis 3 and analysis 4 the elements *Column East*, *Abutment East* and *Abutment West* have the same results of translations. The reason for the same values in translation is that *Column East* and *Abutment East* passed the analysis 3. Therefore, these elements did not change their position when the tool *move host item to as-built* where used.

For the element *Abutment West* in the analyses 3 and 4, *Verity* did not find enough data from the point cloud to specify a position for the as-built position. Therefore, the values are shown as blank. However, these results could have been altered by selecting the element and change the install status to uncertain, then refitting the as-built element to the point cloud. This action was not done to keep the same method for all the analyses.

From the result of analysis 1, 2, and 3 it is shown that it is not much credibility for the method of manually positioning the point cloud and the method of using survey points and coordinates from *Navisworks as e*very analysis gave a different result for total translation. Therefore, Results from the analyses emphasize that the best method for positioning is to have the global coordinates for the point cloud and model before importing to *Navisworks*, then run the analyses with *Verity*.

8.5 Updating the Navisworks model with the use of Verity

Tools *Verity* offers to make changes to the *Navisworks* model are *move host item to as-built* and *export Verity properties to host*. The tool *move host item to as-built* makes the task of updating the model to as-built automated and more effective. However, from the results, it is shown that *Verity* can only move elements to its as-built position in the model in *Navisworks*. Thus, updating models in a different software must be done manually. It is important to understand that the as-built position is the position of the element colored blue in *Verity*. Therefore, it is necessary to do a visual check that the as-built element is placed according to the point cloud to be confident that the element in *Navisworks* is moved to the accurate as-built position when using the "move host item to as-built" tool.

Export Verity properties to host add Values from *Verity* to the elements in *Navisworks* as properties. This is an interesting function for enriching the model and to be sure that information from the analysis follows the model. The color codes provide an excellent visual perspective of the installation

statues for elements. Along with the values added as properties, this tool is a great addition if the model is used to update a model in a different software manually. However, the report form *Verity* should not be excluded as it provides a more visual understanding of the relation between the as-built element and as-designed element.

8.6 Certificate of conducted work

To discuss the relations between manually creating a certificate of conducted work and using point clouds to create the certificate of conduced work it is possible to say that they achieve the same goal. As mentioned in the theory chapter, laser scanners measure distance and degrees for every point in the point cloud and achieve a higher amount of measurements that have the same or a higher accuracy as manual measurements. The trustworthiness of the manual measurements is affected by the risk of human errors, the measurements being easier to fake, and that the measurements can be difficult to measure in places that are hard to reach which in turn reduces the accuracy.

As mentioned in NS 8405 certificates of conducted work is contract based and a necessity in fixed-price contracts. However, in the standard *Nye Veier* uses it is demanded to have certificates of conducted work in the contract, but the standards do not specify how these are conducted. Therefore, the possibility to use laser scanning to produce certificates of conducted work is even more substantiated, and it is shown that the point cloud creates more possibilities with higher accuracy and with a reduced risk of human errors. Also, the Point cloud is an as-built digital 3D recreation of the bridge, and it underlays that the point cloud could be used for other operations, and not only to create the certificate of conducted work.

8.7 Added value from a point cloud

Even if a point cloud is not used to compare against the BIM model it should still provide value. A point cloud provides an accurate and objective snapshot of reality at that point in time. This could be valuable evidence in a potential legal twist.

8.8 Updating the Revit model

Manually updating the *Revit* model can be a very work-intensive process, so tools that can automate the process would be very welcome. Although moving elements around did not pose any issues in this project, updating geometry did. This could be an issue because the group lacks experience with *Revit*. However, with geometry as complex as the superstructure of the bridge, the group believes this to be a challenging task for anyone.

However, from the conversation with a salesman from *ClearEdge3D,* it has come to light that there may come a software extension that allows updating the *Revit* model automatically to as built with *Verity*. Though this sounds promising, this information will not have an impact on the conclusion on how to update the *Revit* model to as built, as it is an assertion from *ClearEdge3D* and the software has not been released to the marked.

8.9 Contract and enterprise form

8.9.1 NS 8405

During the contract phase, the parties agree on approved means of communication, which could include e-mail [25, pp. 93]. A broader definition of accepted electronic communication could make way for BIM tools with communication functions. While project managers and discipline leaders

traditionally communicate by e-mail and phone or meetings, software systems such as *Dalux Field* and *Byggeweb capture* include what is meant to be the primary channel of deviation report communication when implemented in a construction project.[Appendix 13]

The contracting client has a right to conduct controls on all work, and must immediately notify the contractor if errors occur. If the contracting client's control of the construction work becomes to comprehensive, the contractor can rightfully demand additional payments as stated in chapter IV [25, pp. 193]. It would be mutually beneficial for the parties to agree on whether the control should be conducted, and to what extent. These controls and their extent could be specified during the contracting phase. The use of scanning, *Dalux Field* or other means of control would perhaps be examples where the contractor could ask for additional payments. Although perhaps a construction project could achieve net cost reduction by scanning or *Dalux Field*, it would still represent a higher cost for the contractor, which would need to be recompensed in the contract. Likewise, a BIM level 3 requires a shared project server, which represents a significant cost, both building, and maintaining. While the server could decrease net cost, it would be an increased cost for whoever is responsible, and the expense should be covered in the contracting phase.

If parts of the contracting work cannot be evaluated without extraordinary measures or costs at a later time, the contractor can call in for inspection in writing. The inspection shall be protocolled. The contracting client cannot then claim faults [in the construction] which was discovered later, or which should have been discovered in a routine inspection [25, pp. 200]. For example membranes in walls, bridge landings or hidden bearing structures [25, pp. 192]. If a contracting client were to enact this right, it could lead to production downtime while waiting for the controlling personnel or the control itself. Scanning documentation or *Dalux Field* checklists could prove to be tools which increase the efficiency of such processes, or potentially eliminate downtime while not diminishing the quality of the control.

The contracting client is responsible for the time coordination of the parties in the construction project who are necessary for the contractor's execution of the contract. This includes the making and adjusting of the project schedule as per 18.1 and 18.3 in NS 8405. The contracting client shall provide an updated complete overview showing the enterprises and deliveries, and the internal dependencies. If it is not specified, this shall be provided within four weeks of contract signing. It shall be updated for changes and new deliveries and enterprises in the project [25, pp. 266]. If a contractor were to implement a field management software such as *Dalux Field* on a self-initiative, it could be rewarded through an innovation clause in the contract if it was successful [73]. The contracting client could also require the use of a specific field management software, claiming it to be necessary for project synergy. In any case, it should be determined in the projecting phase. Kruse Smith uses *Byggeweb capture* on contracts larger than NOK 20 million, see Appendix 12. Thus, in short, the field management solution in a given project depends on which parties are involved and their experience, the size of the construction project, and the negotiations during the contracting phase.

The contract standard NS 8405 states that documents delivered from one party to another, are not to be made known to others than those in need of them in relation to the construction work, or for later use of the construction, including reconstruction. Neither shall they be used for other assignments without permission from the party that delivered the documents [25]. To ensure this confidentiality, a project organization could make use of authorization keys in the project hotel

server [17]. Decentralizing the server structure could also suffice in maintaining confidentiality [17], but would contradict the Level 3 BIM-requirement of a shared BIM-model or a shared project BIM-server. If a construction project has achieved Level 3 BIM with a shared server or they have a coordination software model such as *Navisworks* or Synchro, one would need ways of communicating changes without breaching confidentiality. The open file format IFC opens for the exchange of model information, but one would need BCF files to communicate information as, for example, text or images [21]. It can, therefore, be stated that a project with a shared project hotel server, with requirements on information confidentiality and flow, would benefit from using reporting software with both IFC and BCF compatibility, such as *Dalux Field*.

Documentation, in general, must be materialized to be accounted as legally binding, meaning conversations are not included. Software, for example, Excel, is an accepted form of documentation and is covered by the provisions above [25, pp. 708]. This aspect of electronic documentation could be specified in the contract standard to remove doubt about what could be accepted as legally binding documentation. As a result of more software solutions in the process of construction documentation and reporting, the contracting client can receive a more substantial portion of the documentation electronically during take-over, with potential benefits in archiving and information security.

8.9.2   NS 8415

Due to uncertainty during the research phase regarding which contract standard was used in *E18 Tvedestrand-Arendal* between the sub-contractor and the general contractor, the group presumed in accordance with the external supervisor that NS 8405 was the one used. This assumption proved wrong as they used NS 8415, and the literature study on the commentary version of NS 8405 was therefore not all relevant. NS 8415 is however approximately equal to NS 8405 [27], [28]. By being aware of the differences in the standards, the preliminary research on the commentary version of NS 8405 was deemed valid in the discussion of NS 8415.

The parties are bound by contract to involve themselves in the betterment of processes in general. *Kruse Smith* needs a reliable system for information flow. From interviews with BIM coordinator and construction manager Appendix 9, we know that *Kruse Smith* uses software solutions *Byggeweb Capture* and *Avvik.com*. These are, however, only partial solutions to the issue of project information flow. As these solutions are used at the same time in the same projects, there is some overlap in capabilities and function, which in turn leads to the same kind of deviation being reported in different ways. There are also some limits to the software itself; model-based reporting, utilization of detail drawings, and live updating of model and drawings. Inadequate communicational severity in that the amount of information and the number of separate e-mails makes reporting efficiency dependent on the recipient's organizational skills can also develop to be a problem according to the discipline leader. A deviation report sent through *Avvik.com* will be received by the project manager as an e-mail, and *Avvik.com* sends a reminder when the deadline is close or overdue. A problem, according to the BIM coordinator, was that the reports appeared the same regardless if he was the primary recipient or just as a carbon copy. This effect of reduced severity of information and should be counteracted with more efficient information flow, where one can easier distinguish between reports and e-mails of varying importance.

From the NS 8415 contract-clauses regarding coordination of reporting procedures for the sake of simplifying reporting of unwanted incidents [56], the sub-contractor can defend an investment and

improvement of their systems for reporting. In other words, one can paraphrase those contract sections when arguing for the implementation of a new system, such as *Dalux Field.* Also, the contracting client is responsible for the coordination of all parties, so one could argue that the contracting client should be held accountable by contract to ensure the interoperability of software, which again could be achieved by requiring IFC and BCF compatibility. In the project E18 *Tvedestrand-Arendal*, the contracting client has not demanded specific software but rather the requirement to conduct, for example, measurements of schedule progress and risk and security analysis. There is, in other words, freedom of choice by the contractor to choose the specific software and procedure, as long as it interplays with the rest of the project [73].

If an injury occurs, the NS 8415 contract requires that the superiors responsible be contacted at the same time as one calls medical personnel and that this superior follows the injured to the treating medical personnel [56]. The Software solutions, like *Dalux Field*, has an integrated project hierarchy and could aid in an efficient and correct information flow, meaning that the right personnel is contacted, and the incident is correctly archived.

In the contract extract above about accidents, demand for routine appears. This routine shall contain that communication should both go to the involved and responsible personnel, and upwards in the organization for measurement and archiving. To practically achieve this routine, the information flow could be automated. However, everyone does not need the same information, and the information in for example a personal injury event could be parametrized, meaning the detail level of the message can vary from mere notification to a full report for archiving depending on who is the recipient. Also, the messages should only be distributed to the necessary personnel. An accurate information flow could improve the efficiency of task handling, and maintain the importance/integrity of e-mail [56].

In the chapter regarding consequences on the neglect of HSE and notifying, in the contract between *AF Gruppen* and *Kruse Smith*, it is stated that the sub-contractor shall only use their most qualified and motivated personnel [56]. Also including the contract statement that all deviation reports are to be categorically viewed as positive, one can see a clear mandate to improve and conduct reporting. Combined with the innovation contract clause, where cost reduction is rewarded, sub-contractors are well within the bounds if implementing field management software and asking for BIM models in the tender.

8.9.3   The contract's impact on model-based reporting

According to a BIM coordinator and a discipline leader in an interview, the use of models in a project should be decided during the initial establishment of the contract, see Appendix 9, or it will otherwise not be profitable to keep the model up to date with the newest updates. Furthermore, a model imported to *Dalux* in which the most recent updates have not yet been made can turn out to prove itself redundant. For *Dalux* to be utilized to its full potential, resources for modeling has to be decided upon in the contracting phase.

8.10   Dalux

As tasks are being created, color-coded dots will appear on the floorplan. The issue regarding the fact that these dots are connected to a coordinate and not an element in the model is that it weakens the

accuracy of the report overview. One would have to enter each report to know what exactly is reported. This cannot be seen on the floorplan itself because the dots are connected to the coordinate in which the one is creating the report was located at the time. For example, it is possible to mark an element and create a task from as far away as the model allows. The floorplan would still show that the report has been created at that spot, which might cause some confusion as to which element has a deviation. Possibly, if reports were instead connected to the model elements, this confusion could be avoided.

Any 2D drawing in PDF format can be imported to *Dalux Field*. Theoretically, this means that any map base drawing could be used as a floorplan and a foundation for reporting. This would again mean that *Dalux Field* could, in fact, be used in road construction without a sufficient model. However, the location for the report and the report itself would be somewhat vague as one loses the possibility to highlight it to a specific element. This is a result of not using a model.

The reports and task manager in *Dalux Field* is somewhat model-based. However, as the viewer requires floorplan drawings as a base for the different floors in a construction, it is also drawing-based. This may seem inconvenient because the *Revit* model is built up using levels and it is possible to create views anywhere in the model to obtain the desired plan. This should also be possible in *Dalux Field* for several reasons. Firstly, any change to the model would also automatically update the floorplan. Secondly, the ability to create custom views would enable further flexibility. The fact that the viewer has a cutting tool, but cannot define a cut as a drawing leads to unnecessary measures required for the viewer to work correctly. The ideal scenario is that the model is the only requirement for smartphones and tablets.

Dalux Field does not handle sequencing data, also known as 4D. It is being worked on for future updates of the software, but as of today, *Dalux Field* cannot be used for progress planning as a complete program. If a 4D feature could be implemented into the software, it would enable comparison between deviation reports and progress, which could be interesting for post-construction evaluation.

For any company to utilize a field management tool such as *Dalux Field* to its full potential, the model needs to be on the sufficient level of detail. This requires a lot of time and resources which in turn is expensive. This might be part of the reason as to why most contractor companies choose to use a low-detailed model for, for example, visualization rather than a highly detailed model for documentation, reporting, and effective field management. Additionally, the model needs to be updated in pace with future plan revisions for it to be correct and usable. Again, this is costly and time-consuming. Most contractor companies do not see the reward from putting so much time and resources into the model. This might not be the case if the modern business model was more favorable towards BIM because the degree to which BIM is beneficial to a company is entirely contract decided.

Issues regarding *Dalux Field* on bridges could be improved if the larger components were to be split up into several, smaller components. This solution, however, would have to be done within the modeling program (for example *Revit*), as *Dalux* does not possess the ability to alter the original model. Regarding bridges, it is also crucial to add items that are not originally part of the designed construction. During the construction phase, there are significant amounts of scaffoldings and formworks as well as other temporary components. Most reports on RUH are located at these components. It is, therefore, a flaw that the sender may not pinpoint the exact location of the

report/task for the receiver to react. However, most construction managers would be able to build a mental picture of the situation even without pinpoint accuracy, but with the use of pictures attached to the report. This could be solved by improving the model's level of detail.

It is proven in the results that *Dalux Field* has its issues with no 4D-compatibility, inability to generate floor plans from the model within the software, can only do IFC element information, and the type of information one can report. This was, however, not made clear until the software was already decided upon, and the selection process was done. The time it took to get the license, explore the software, and compare the properties was so long that one could not have begun searching for another alternative when *Dalux Field*'s shortcomings were fully discovered in week 14. The decision was, therefore, to continue the use of *Dalux Field*, even though it was not the optimal solution.

A possible source of error could be that *Dalux Field*, in fact, was an improvement from *Avvik.com* and *Byggeweb Capture*, which in turn made it easier to believe that it was what the project should be based on. Also, the response from *Dalux AS* was quicker and better than other developers, and the information was easy to access and use, which in turn improved the impression of the software itself. Other software developers had even more available licenses, but it was more difficult to access information, and we were met with slightly too much information. In short; *Dalux* responded within the same week, gave full student licenses to the entire group, linked relevant information, and offered a skype-walkthrough of the software. *Autodesk* responded slowly, sent several irrelevant e-mails with commercials and such, and when they finally responded it was an auto-generated e-mail which passed us on to their webpage.

A weakness in the method when it comes to the report part of the project is that we got the license for *Dalux Field*, but we did not have access to *Avvik.com* and *Byggeweb Capture*. Consequently, while we managed to conduct tests for ourselves in *Dalux Field*, the information regarding *Avvik.com* and Capture had to primarily come from interviews, conversations, online websites and videos and literature studies. This may have negatively affected the credibility of the comparison as our personal experience may have fallen in *Dalux*'s favor. Also, we learned from the interviews that the solutions from *Avvik.com* and Capture had several flaws that the BIM Coordinator and Discipline Manager disliked. As a result, we got the opinion that today's solutions for reporting were insufficient. Even though this might have been true, it would still weaken our objectivity for the different software which in turn could cause us to subconsciously want to prove that *Dalux Field* is the best solution.

Another factor that perhaps tipped in favor of *Dalux* was the license price. The selection process was profoundly affected by the access to the license and their price, both for the group to obtain trials, but also for eventual companies to implement the software. Rather subjectively, cheaper alternatives were favored.

A possible source of error could be our confidence in a given method, regardless of the quality of analysis. Meaning information gathered through conversations and interviews with professionals from *Kruse Smith* and *Dalux* AS were trusted more than information gathered independently by the project group. The confidence in professionals above ourselves and the weighing of the method of interviews above source material research overshadowed the fact that the interviewees could perhaps be biased.

Initially, the knowledge-base in the group and among the supervisors regarding BIM-solutions for reporting and information-flow was rather small. This represented a potential and justified the

project research question. However, the same lack of knowledge on the subject made that any solution was met with optimism, as they at least were better than today's solutions. The atmosphere in the project group at the time of deciding upon *Dalux Field* was confident, as the project had in a short period finally gotten software licenses, software information and tutorials, go-signal from both supervisors on the research question, and coincidentally at the same time gotten access to the case facilities at E18. Additionally, the decision was to be made within the week, according to the project schedule. The power of judgment in the situation might have been affected by this.

Dalux Field was still used as base software for the project, and as the group is aware of its shortcomings and how these could be improved upon in the future, the research could still be regarded as credible and useful. Also, the project success is not measured by the capabilities of *Dalux Field*, as it may have affected the thesis objectivity.

Interviews [34, 73] and some anonymous comments in the survey stated that common file formats are necessary for BIM to be effective in the construction industry. The IFC format has enabled the exchange of bulk model information, and the collaboration between for example architects in *ArchiCAD* and BIM coordinators in *Navisworks*. Thus, any software a construction contractor may consider implementing should be compatible with IFC.

Given that a construction project has a BIM model and a construction engineer discovers a deviation in the bearing structure, the deviation report would need to either contain the entire BIM model in bulk or not include the model at all; The IFC model cannot be split up or treated in an automated process. Also, the construction engineer would need to describe the location and nature of the problem regardless of the IFC model being imported to the recipient's software or not, as the IFC model in itself does not carry any information other than the model itself. Having to describe the problem manually would lead to extra work for the engineer, and also be a potential source of error in both the description and interpretation. IFC does not enable the exchange of information in text, pictures or other mediums, as described in chapter 3.2.5 OpenBIM. BCF enables reports with information the IFC format cannot include, which would be necessary for solving a given deviation as described in the paragraph above. BCF can either be sent through plug-ins in the software, like in *Revit* or be sent by e-mail. Software like *Dalux Field* also archives the reports sent, which could provide for example aid in a legal matter if the report contained the necessary standardized information.

The software solution chosen by a given contractor for deviation reporting would, therefore, be more efficient and be more apt to fully utilize the BIM if the software not only is IFC compatible but also supported the BCF format.

To increase the quality of the results of the conducted interviews, a possible method would be to do a couple more interviews to gain a perspective from several professionals with possibly a different opinion. This could create a better foundation for cross-checking of information. As only a few interviews were in fact conducted, and that two of these were from the same contractor company, our results might have been one-sided to a certain degree. Still, the issues brought up in the interviews are real in the construction industry, giving the research question for this project a relevancy basis.

Fulgt opp flere av trådene vi fikk gjennom intervjuer og samtaler. Dersom man leser gjennom alle referatene, er det flere eksempler på personer som aldri ble kontaktet, og emner som ikke ble

undersøkt. Dette var ofte fordi man hadde andre fokus, eller at det var et nytt møte dagen etterpå som tok oppmerksomheten. Dette ville uten tvil ha endret prosjektarbeidet, og kunne potensielt endret vår problemstilling.

Summarized, model-based reporting by using a field management software such as *Dalux Field* is quite feasible if the necessary precautions are made. It requires a detailed and updated model, which again might have to be contract-based for any company to benefit from it. *Dalux Field* has shortcomings when it comes to 4D sequencing data. The industry could benefit more from *Dalux* if 4D were implemented. Earlier circumstances in the project affected the group to choose *Dalux Field* as model-based reporting software, even though later discoveries have revealed some issues. Although the software tested in this thesis was incompatible with 4D BIM-data, there are indications that this will be developed for future use.

8.11   Dalux vs. capture

Statistics provided by *Byggeweb AS* on the use of *Capture* in *Kruse Smith* shows tendencies of cost reduction and efficiency increase, see Appendix 13, [37]. As shown in table 7-7, *Dalux Field* is equal or better than *Capture*, and one could argue that the benefits of using *Capture* would apply to *Dalux Field*.

The results show that *Dalux Field* and *Byggeweb Capture* share several functions and qualities (see table 7-7) except a few differences. *Dalux Field* can use both drawings and models, while *Capture* only uses drawings. This functions alone creates more options for *Dalux* than *Capture*. 3D views facilitate a wider variety of perspectives, which again may assist in creating a better overview of a given situation on a construction site. Contract and enterprise

Another noteworthy difference between the two software is that *Dalux* can export reports as BCF files. This means that *Dalux Field* offers a potential aid for an integrated BIM method based project, while *Capture* mostly offers a method for reporting. It can be argued that *Dalux Field* is more adaptable for future developments when it comes to digitalizing the construction industry, based on the BCF capability.

Byggeweb Capture provides an almost equally good reporting tool as *Dalux Field* in terms of reporting itself. However, if a contractor plans on making their workflow more digitalized and BIM-based, *Dalux Field* could accompany this development on a higher level than *Byggeweb Capture*.

9. Conclusion

The conclusion will first answer the secondary questions and then lead up to the original question.

- How can 3D-scanning be used to document whether the construction is built according to the BIM-model?

It is possible to document deviations between the construction and the model, by only using a point cloud and doing a manual visual comparison between the model and the point cloud. However, it is significantly more effective when pairing it with tools that help automate the process, like *Verity*. Because trusting the data is essential to use both the point cloud and the deviation from the model as proof for the execution of the project, it is recommended to use accurate coordinates, for example, survey points, to prove whether an element or construction is correctly placed, relatively to both local and global coordinates.

- How can the *Revit* model be updated from "as designed" to "as built" using a point cloud of the bridge?

No tools were found for automating the process of updating the model from as designed to as built, and until solutions for this appears this must be done manually by the likes of BIM technicians. By linking the point cloud and the *Revit* model inside *Revit*, the user can move the elements until they fit the outline provided by the point cloud. It is recommended to use the report of a deviation analysis as a checklist to ensure no element is forgotten.

- How can a procedure be composed for 4D model-based reporting on deviation found in the construction phase?

A procedure can be composed for model-based reporting by implementing a more detailed level of BIM to the existing reporting protocols. This implementation will require specific demands from the contracting client in the contract. Regarding 4D, there seems to be no solution that provides sequencing data integrated into a field management software for model-based reporting as of today.

How achievable is the use of 3D-scanning for model-based documentation, and how can a project accomplish model-based reporting in the horizontal construction industry?

The use of 3D-scanning for model-based documentation is achievable but requires expensive, specialized equipment and software, and operators that have the necessary competence to exploit the potential. Some of the main benefits of using 3D-scanning and model-based documentation are the high accuracy and the objectivity it provides, the potential for reducing human errors, and the possibility to automate tasks.

Projects in the horizontal construction industry can accomplish model-based reporting by allocating more resources into creating models with sufficient detail level and their utilization. However, this requires the modern business model to accommodate digital development.

10. Recommendations for future endeavors

It would be of interest to do a quantitative study on the effect of model-based reporting and 3D scanning, and more specifically, *Dalux Field* and *Verity*. This study could include measures on efficiency and economy. For example, if 3D scanning reduces the number of errors, can monetary gain can be associated with the improvement, and how beneficial would it be? Also, it would be interesting to investigate to what extend *Dalux Field* handles HSE, and to do a complete study of the entire Dalux suite of software and its possibilities.

The contract form is a significant aspect of implementing BIM. It is of a high interest to investigate how the current contracts affect BIM implementation, and what changes could be done to further the implementation of BIM.

11. References

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