# Early Validation using Architectural Overviews (A3AO) a Case Study in an IoT Consultancy

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**Abstract**. This paper focuses on the use of A3 Architectural Overviews (A3AO) for early validation of stakeholder needs and system concept as part of a tender proposal in an IoT consultancy. Tender proposals are an essential part of communication between most companies working in the engineering field. Often with high-tech companies, a technical knowledge gap exists between the different stakeholders reading tender proposals. This knowledge gap increases the risk of miscommunication and wasteful work. A real-life case from an IoT consultancy tendering an IoT concept for a processing facility forms the basis for the research. Applying an action research approach, the researchers tailored the A3AO framework to fit within the consultancy's work flow and developed an A3AO describing the tendered system concept. The customer received and later accepted the tender proposal including the A3AO containing the stakeholders' problems and needs, a concept solution, and a roadmap detailing further work. In this study, we collected data from observations, semi-structured interviews, surveys, and a follow-up questionnaire to the customer. The study found that the A3AO functions as a tool for early validation and that it helped bridge the knowledge gap between the consultancy and customer. The study also raises questions and criticism regarding cost and complexity. The consultancy later decided to implement A3AOs in future proceedings.

## Introduction

**Architectural Overviews (A3AO).** The A3AO is a tool first proposed by P.D. Borches (2010) that coalesces large amounts of information and data onto a single A3 sized sheet of paper using various visual and graphical aids. The purpose of the A3AO is to be a tool for effective communication of architectural knowledge and as such it is a promising tool to support early validation. Our aim in this study is to research how A3AOs may support early validation of system concepts as part of the tender process using the consultancy as our research vehicle. In our study, we apply the A3AO in a tender proposal where the A3AO summarizes the customers' processing facility, a proposed IoT system concept, and includes relevant information such as a budget, a cost breakdown, and a project timeline.

**Early Validation.** Validation is one of the ground pillars of Systems Engineering (SE) and the SEBoK (2022) refers to Wasson, who described validation by asking: *"Did we acquire the RIGHT system to meet the User's validated operational needs?"* (Wasson, 2006). Wasson listed various methods for performing system validation, such as qualification tests and field trials. A challenge with Wasson's viewpoint is the considerable effort it takes to undergo these tests and that some are only possible to do late in development. Pairing this with the emergence and apparent foothold of the agile methodology, where fast-paced sprints are slowly becoming the norm in large parts of the R&D market, there is a significant risk of miscommunication between stakeholders. Customers of companies using the agile methodology often expect results in weeks instead of the traditional months or years. This transition to a faster pace presents a challenge as this way of working differs significantly from what large parts of the SE theory describe. Because of these factors, engineering companies need to understand the customer's situation, needs, and pains faster than before.

Kjørstad (2022) argued that applying visualization, creative techniques, and sense-sharing will help bridge the gap by gaining insight into operational needs, customer value propositions, and business cases more rapidly. To facilitate this, Kjørstad (2018) proposed several methods for quickly and reliably eliciting customer needs by running co-creation sessions. Muller (2011) emphasized that we need more informal working methods to support exploration and context understanding, and in 2020, Kjørstad, Falk and Muller (2020) started the development of a toolbox that recommends multiple creative methods for early validation. To narrow the gap between stakeholders, a more human-centric approach is beneficial, and we are starting to see SE researchers taking inspiration from the design space by incorporating design techniques (Selvaldson, 2022a). During the study, we tested methods usually found in the design space, such as collaborative canvases, sketching and Gigamapping. The results from the sessions formed the base for creating an A3AO. The A3AO were used in further discussions with the customer and internal stakeholders in the consultancy.

**Research Context.** This study is conducted in a small-and medium sized IoT engineering consultancy named Sensorhouse. The consultancy is a subsidiary of the software company Digitread-Connect developing industrial IoT applications and data processing tools. Sensorhouse provides customers with knowledge to correctly choose, install and maintain industrial IoT systems fit to the customer's specific problems and needs. The consultancy's tendering process utilizes short sprints, where the average project duration is around three weeks from initiation to the customer receiving the first deliverable. The customer can choose which sensor supplier to use after the sprint and is not bound to continue working with Sensorhouse. The first sprint culminates in a tender proposal detailing Sensorhouse's understanding of the customer's problems, needs, possible solutions, including a system concept and appropriate sensors, and a roadmap for further engineering and implementation.

**Industry Case.** The industry case is an IoT system concept to a customer that owns and operates a processing facility producing a substitute for traditional fertilizer. The customer contacted Sensorhouse for consultancy in finding and installing various sensors that collect data from multiple stages of their process. They will use the sensor data to gain more insight and learn how to improve their current manufacturing process. The process facility turns biowaste into nutritious fertilizer using a rapid composting technique. The end products are fertilizer and bio coal, sold primarily in bags of 1 $m^3$, with farmers as the primary target group. The customer also sells products in smaller packs for home growers and hobby gardeners.

**Problem and Research Questions**. Tender proposals are the backbone of the consultancy's business and part of their early deliveries to the customer in the form of a written report. The tender proposal is formally accepted or rejected by the customer after review. Sensorhouse has often observed that the stakeholders receiving their tenders holds varying degrees of technical knowledge about the proposed concept. There is a technical knowledge gap between the different stakeholders reviewing the tender. This poses a substantial risk for miscommunication, wasteful work, and loss of contract. In this study, we investigate if A3AOs can bridge that knowledge gap, ensuring that the IoT system concept is presented in the best possible way and in a style that allows stakeholders without deep technical knowledge to read and understand the presented information.

The study investigates the following main research question and sub questions:

*How can A3AO improve Sensorhouse's early validation and communication in the tender process?*

- *How can A3AOs be used to avoid miscommunication with customers?*
- *What are the benefits of using A3AOs in workshops and tender processes?*
- *What may be the challenges with the A3AO modelling format for tender processes?*

## State of the Art

**A3 Architectural Overview.** P.D Borches (2010) first suggested the A3 Architectural Overview (A3AO) in his PhD thesis *"A3 Architecture Overview: A Tool for Effective Communication in Product Evolution"*. During the research, Borches developed and used the A3AO in projects in the Philips Healthcare department, proving it to be a powerful tool for effective communication. In Borches' original work, he proposed using two A3 pages (front and back of the paper), where the front side consists of a structured model, and the back contains structured textual information. In both cases, it is encouraged to use visual representation to aid understanding. The primary method of collecting the data used in Borches' A3AO was using Reversed Architecting. Borches explained that the A3AO should not be considered complete, formal, or executable but rather an artefact to support effective communication of architectural knowledge.

**Adaptation and newer usage of A3AO**. In the years after the Borches work, various institutions have published studies using variations of the A3AO. The work of Hooft, Wiulsrød, and Haugland's is notable and will be investigated in the next paragraphs.

D. Hooft, Kroon, Ommeren and Bonnema (2020) interpreted Borches's work, where they developed and tested a version of the A3AO tailored to new product development instead of reverse architecting. During the study, they created an A3AO template that was presented and used in an organization otherwise unfamiliar with SE practices. The following year, the organization made more than 40 A3AOs and fully integrated the use of A3AO in the new product development process. A large variety of stakeholders positively received the A3AOs.

Haugland and Engen (2021) published a study on the application of A3AO in subsea front-end engineering studies, where they developed and validated an A3AO. They used the A3AO primarily in early-phase studies and reported that the participating company responded positively. They showed that the A3AO supported knowledge sharing and created a method for building a common understanding. Furthermore, Wiulsrød, Muller and Zhao (2022) published a study using A3AO in the oil and gas industry. They named their variant Operational A3 (OPA3) to convey the closeness to the case's practical and "hands-on" environment. During the study, they developed an architecting process tool for a company which successfully increased project performance.

**Conceptual modelling**. Models have become an integral part of most people's everyday life. Whether it is to create a shared understanding between engineers or to describe where you find your place in a company hierarchy, models are used to take a real-world aspect and simplify it enough to represent it visually or conceptually. The A3AO consists of multiple conceptual models. Conceptual modelling is just one of many ways to create a model, and it likely has as many definitions as there are other models. Engen (2022) tried to dissect some of these definitions in her dissertation about Conceptual Modelling for Architectural Reasoning. To quote but a few from her paper, Harrison and Waite (2012) called it: *"an abstract, simplified representation of a system of interest"*. Lavi, Dori and Dori (2020) chose the wording: *"the product of the system representation process"*, and Muller (2015) defined it as: *"models that are sufficiently simplified to help architects to understand, reason, communicate and make decisions"*. Last but not least, Fujimoto and Loper (2017) said that all models are, or at least contain, conceptual modelling since they simplify the real world.

**Workshops and creative sessions.** Workshops are integral to most companies that do creative work. The consultancy in this study uses workshops to retrieve customer information and as an internal tool for creating products, especially in the initial concept phases. In this study, we also looked into using creative sessions and Gigamaps to create a better environment for innovation. A large part of workshops is to create a platform for innovation. Kjørstad (2021) argued that there is a distinction between two forms of innovation; incremental innovation and significant innovation, and that most mature companies fall sooner or later into incremental innovation since it has a lower risk and is more predictable than significant innovation. Co-Creation is a term used to describe different creative techniques that aim to support significant innovation. Significant innovation is much harder to achieve than incremental innovation, but if done correctly, it can completely transform companies, sectors, and even entire industries. In her paper, Kjørstad (2021) proposed multiple techniques for achieving significant innovation, such as Gigamapping, Ideation and Brainwriting.

**Gigamapping** is a primary segment of Systems Oriented Design (SOD) originating from the Oslo School of Architecture and Design (Sevaldson, 2018). Selvaldson (2022b), one of the pioneers and architects of SOD, described Gigamaps as a *"very extensive map that includes large amounts of information across different scales and categories"*. Gigamapping is a method that allows practitioners to get a better understanding of very complex systems. Gigamapping enables the user to gather and comprehend vast amounts of data by drawing from a designerly way of dealing with super-complexity while using established methods and perspectives otherwise found in systems thinking. (Sevaldson, 2011).

## Current Consulting Workflow

This chapter describes the current workflow for consulting at Sensorhouse. For most customers, Sensorhouse uses a four-stage process; Greeting – Develop – Test & Verify – Scale (Figure 1). The subsequent paragraphs describe each phase.

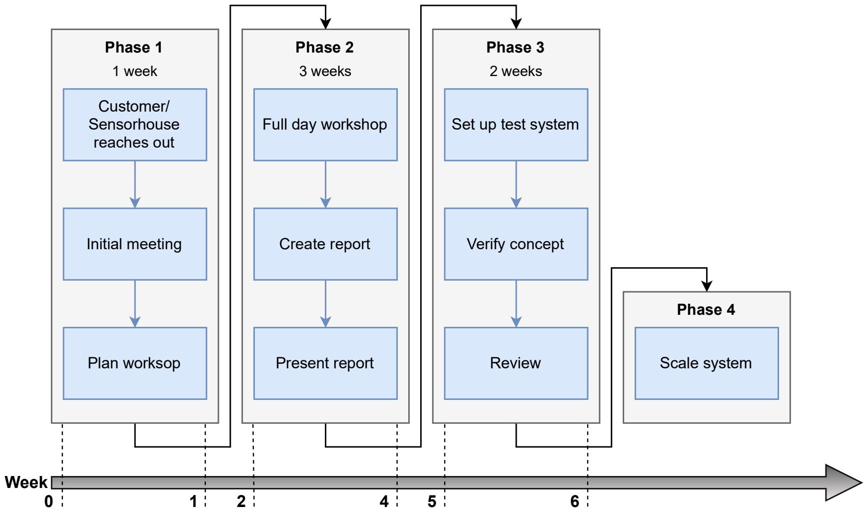


Figure 1 – Consulting workflow

**Phase 1 – Greeting.** Phase 1 consists of preliminary meetings to get to know each other. Usually, this phase involves two to three sessions, covering greetings, brief technical presentations, and agreements such as NDAs, and similar B2B discussions before executing phase 2.

**Phase 2 – Develop.** Phase 2 starts with a full-day field visit and workshop with the customer. The consultancy uses workshop methods and tools collected from various literature, with various personal tweaks. Sensorhouse primarily meets two distinct kinds of customers, one with good technical knowledge and the other where the customer does not have it. Since Sensorhouse specializes in sensors and IoT, the customers often need to measure a physical value, either with existing infrastructure or a new one. After the field visit and workshop, a development sprint begins, which usually lasts three weeks. Following the sprint, Sensorhouse delivers a tender proposal describing the system concept and how to proceed. If the customer approves the concept, phase 3 begins.

**Phase 3 – Test & Verify.** In phase 3, the consultancy facilitates installing a small-scale system test to verify the proposed concept. The agenda of this phase is volatile as the complexity, size and operational availability of projects differs significantly. After reviewing the system, the customer can proceed with phase 4.

**Phase 4 – Scale.** Phase 4 of the project is the scaling of the proposed system. When projects enter this phase, the consultancy role changes from a development partner to an assistant project manager or supplier. Phase 4 is not part of the scope of this study.

## Research Methodology

**Approach**. According to Muller (2012), it is challenging for SE researchers to verify and prove that the methods they develop work when used by industrial practitioners. He argued that studies such as this one functions as a validation tool as we gradually build up a collection of case studies that support (or invalidate) the methods and theories presented in the SEBoK. Going back in time, Checkland and Holwell (1998) discussed a similar situation in their paper: Action Research: Its Nature and Validity. They proposed Action Research (AR) as a method for these situations. A primary tenet in action research is to plunge yourself into real-life cases. They defined it as follows:

> "*A researcher immersing himself or herself in a human situation and following it along whatever path it takes as it unfolds through time*".

Checkland and Howell also pointed out an essential fact about AR: we must accept that social phenomena are "*not homogenous through time"*. This conflicts with the typical scientific model, where researchers can expect to find the same results hundreds of years in the future: A molecular scientist will always come to the same conclusion when combining two substances. The essence is that AR is considered correct today but may not be valid in the distant future, as our society, understanding, ideas, ways of working and thinking will inevitably evolve through time.

**Research design.** In this study, we used a research design (shown in Figure 2) where we worked through the four steps, Explore, Apply, Evaluate and Validate.

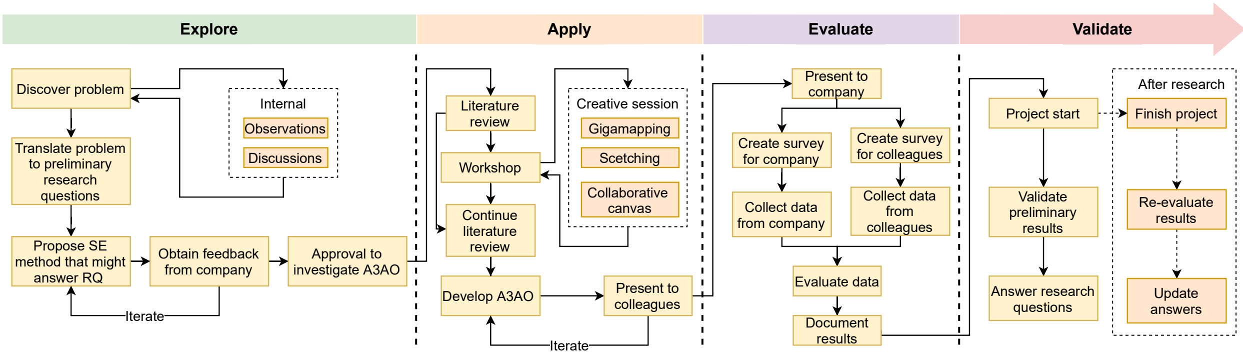


Figure 2 – Research Design

**Step 1 Explore (Figure 2).** In the exploration phase, the goal was to discover a problem within the organization and find an appropriate SE method that might tackle that problem. This process was iterative, going back and forth with the company supervisor before getting approval on a specific method. The primary means for discovering the problem were observations and informal discussions with the management and employees.

**Step 2 Apply (Figure 2).** The application phase began with the literature review. A customer agreed to participate in the study during this stage. Because of the real-life nature of AR, this situation opened two parallel workflows, which led to the workshop's conduction during the literature review. The topic for the workshop was a field visit followed by a creative session, which resulted in a Gigamapping focusing on the production process. During the session, we used a canvas to cover a table and asked the participants to sketch the manufacturing process. We then used this sketch to place points of interest where more information could be beneficial, such as a temperature or humidity reading. We then listed why they thought this information was important. This canvas formed the basis of the Functional and Operational view in the A3AO. After the workshop, we continued the literature review alongside the development sprint in the consultancy. The A3AO was developed and iterated before continuing to the next phase.

**Step 3 Evaluate (Figure 2).** To evaluate the A3AO, we started focusing on internal experiences. For this process, we gathered data using surveys and semi-structured interviews. We then presented the A3AO to the customer and got feedback directly after the meeting, followed by a response on a follow-up questionnaire two weeks later.

**Step 4 Validate (Figure 2).** To validate the study's findings, we held a meeting to discuss the process and current standing of the project. Again, because of AR's real-life nature, this proceeding had to be conducted before the consultancy fully completed the project. We strongly recommended scheduling a secondary validation a few months after the delivery.

**Likert scale survey.** To gather diverse perspectives and technical backgrounds, we employed a survey based on the Likert methodology (Likert, 1932). The survey participants consisted of employees from Sensorhouse and Digitread. Digitread Connect provided the project's application and cloud management software and was an integral part of the proceedings. The survey focused on the benefit and concerns regarding specific areas of the A3AO, the experience of using A3AO and the value for the consultancy and customer. Using the Net Promoter Score (NPS), we singled out the promoters and their willingness to recommend the techniques as described by Reichheld (2003). This study considers the promoters as those who respond strongly agree, while detractors are the ones responding neutral, disagree, and strongly disagree. “Agree” is neither promoter nor detractor.

**Internal Interviews.** We chose to use semi-structured interviews because of the intrinsic quality of exploration and discovery (Muller, 2013). We conducted all interviews in person. The interviews lasted between 30-

60 minutes. The participants consisted of employees in Sensorhouse and Digitread-Connect. During the interview, we discussed the A3AO from start to finish, tackling one view at a time. We started by explaining the motivation for the view in focus, followed by a description of the content. After the participant was familiar with the content, we discussed the benefits and possible drawbacks of the view. We then prompted the participant to give any recommendations for possible changes.

The interviews contributed to a better understanding of possible improvements, thoughts and ideas around the development and use of A3AO in the consultancy, which supplemented the findings in the Likert scale survey. Table 1 shows the participant's role in the consultancy and years of experience in the field.

Table 1 – Interviewed participants.

| Role in consultancy | Experience in field |
|---|---|
| **Chief Executing Officer Sensorhouse** | 17 |
| **Chief Executing Officer Digitread-Connect** | 15 |
| **Industrial developer** | 3 |
| **IoT cloud developer** | 3 |
| **Industrial developer** | 2 |
| **Edge developer** | 2 |

**Follow-up questionnaire.** After presenting the A3AO to the customer, we sent a follow-up questionnaire. The customer had two weeks from the meeting before answering the questionnaire to give them sufficient time to discuss and process the experience.

## A3AO Development

The motivation for developing and using the A3AO is to reduce the amount of technical documentation and, simultaneously, make that documentation easier to read, thus removing the knowledge gap. Because of this, we decided only to use one side of the A3 sheet and focus on using as many visual aids as possible. The A3AO uses some of the same views as provided by Borches (2010), "Functional view", "Physical view", called Operational view, "Quantification view" called Points of Interest & Cost and "Visual aids" called Maintenance and Development & Installation plan. We also added the Proposed System View.

The functional and operational view was a direct product of the workshop. We transformed the workshop canvas into digital form, which, after some iterations, became the functional and operational view seen in Figure 3 – complete A3AO (full size in Appendix C). The subsequent sections describe each view in more detail.

**Functional view:** The functional view breaks the customers' process into functions of three layers. The functions trace the process from receiving raw materials (manure, food waste, and water) into finished bio-coal. The subfunctions between the first and second 1. level functions are made with smaller icons since they are not in the scope of the consultancy project.

**Operational view:** The operational view depicts the customer processing plant in a model that represents the real-life layout of the factory. It shows the input and output of the system and includes a legend to explain the different visual objects. Tracing along the conveyer belt (dark grey color) shows how the biomass travels from the mixer, through the decomposition tanks, down to the dryer and out into packaging. The air ducts (light grey color) show the removal of gasses from the decomposition tanks and the transportation of hot air to the dryers. We indicate a general position of the proposed sensors with the yellow sensor icons.

**Proposed system view:** This section outlines the consultancy's proposed system. If the customer agrees to continue with the project, this view is essentially what the customer buys. The model shown in the A3AO uses minimal technical language, a more technical version detailing product numbers, communications protocols, physical interfaces and so on should be created while developing the concept. The technical version is only shown to the customer if they need further clarification on how the system operates.

**Points of Interest (PoI):** The Points of Interest show the intercept points between the customer and the consultancy. Each PoI is assigned a figure, in this case, a numbered red star. The textual information briefly explains the reasoning behind the PoI. In this case, the PoIs (except PoI 3) detail the sensor parameter, general sensor placement, stakeholder requirements, motivation, and exposed environment. The PoIs facilitate a link between the different views, making it easier to understand where, why, and how the components of the system operate in real life.

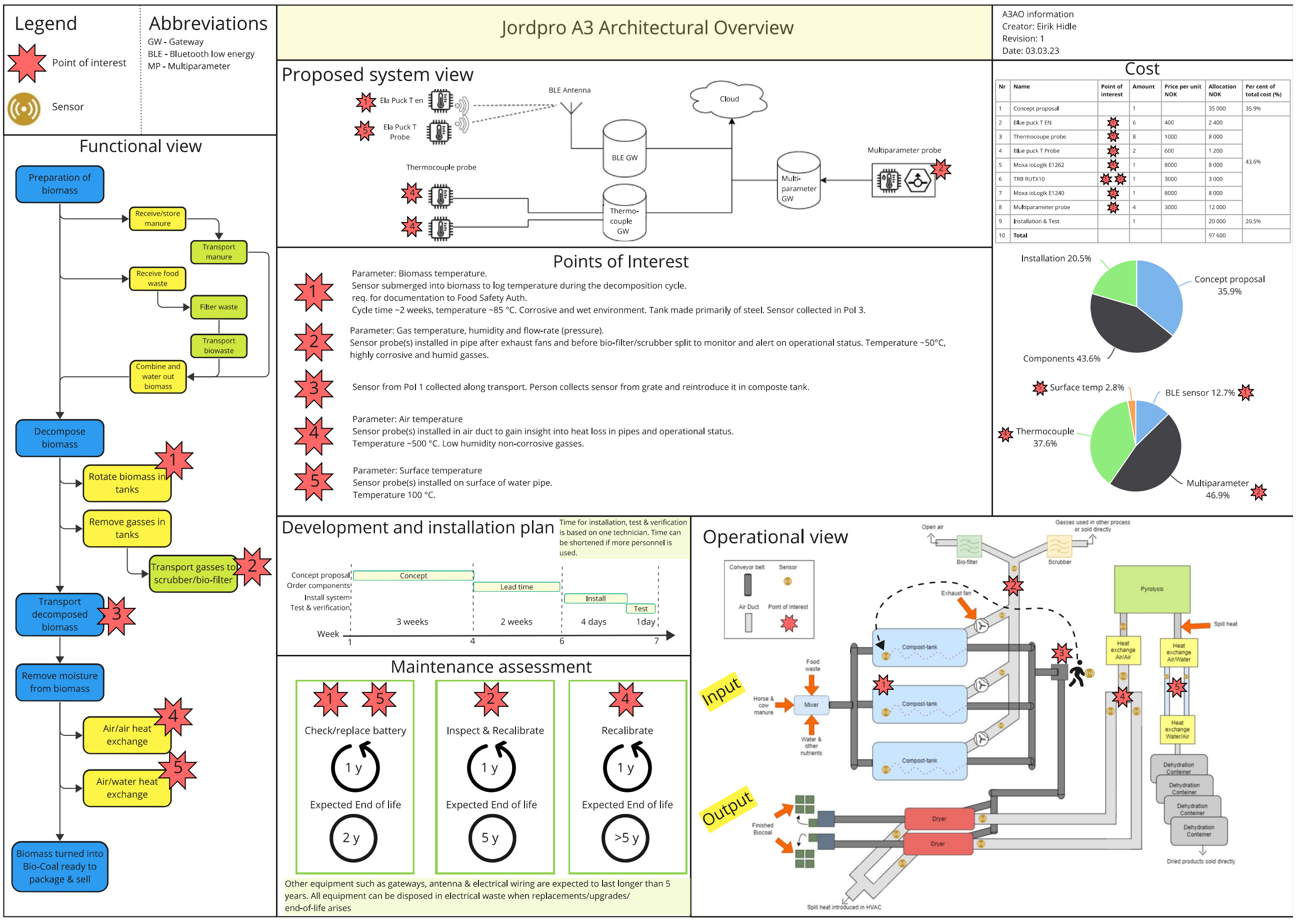


Figure 2 - Complete A3AO (full size in Appendix C)

**Cost**: The cost view shows a table with the expected cost of the different components of the system. This table includes the price of the components, concept development and the cost of the installation process. In addition, we used two pie charts to indicate the breakdown of the total cost and the breakdown of each subsystem cost.

**Total cost breakdown:** This first pie chart shows the installation, components, and concept development price distribution. This chart is important as a sales argument for the consultancy since it conveys our hourly price against that of the components.

**Subsystem breakdown:** The second pie chart shows the cost distribution between each subsystem. This chart is vital for the customer to see and understand as it conveys cost/benefit. For instance, in our case, it was crucial to point out that the cost for the thermocouple subsystem more or less equals the cost of the multiparameter subsystem while providing twice the amount of sensors. The customer can better decide what to prioritize by seeing a comparison such as this. It may be that a system containing 16 thermocouple probes provides more value than the proposed eight thermocouples plus four multiparameter probes.

**Development and installation plan:** The view shows the expected completion time. Often, there are long and varying lead times on components, which can impact the decision-making process. The installation time is also essential to convey to the customer, as this process might cause downtime or other complications with the customer process.

**Maintenance assessment:** The maintenance assessment conveys what the customer is required to do after installing the system. This work will often include inspection and recalibration. The lower part of the view shows time estimates for end-of-life and disposal instructions for the components.

## A3AO Evaluation

We employed four different methods for evaluating the A3AO in the study. For internal feedback, we conducted a Likert Scale survey and interview process. All participants received a thorough walkthrough of the A3AO before answering the survey. Afterwards, we interviewed the same participants. For the external feedback, we presented the A3AO in a meeting where we received direct verbal feedback. After the meeting, we sent out a follow-up questionnaire to the participating consultancy.

**Internal survey results.** Figure 4 shows the survey results from the internal Likert scale survey. The NPS shows a general confirmation that the employees liked using A3AO. Three questions stand out, "Overall the A3AO is easy to understand" and "The A3AO delivers more value than the cost of creating it" received a negative NPS, and the question "Overall the A3AO improved my understanding of the project as a whole" were the only question that received a full score on strongly agree.

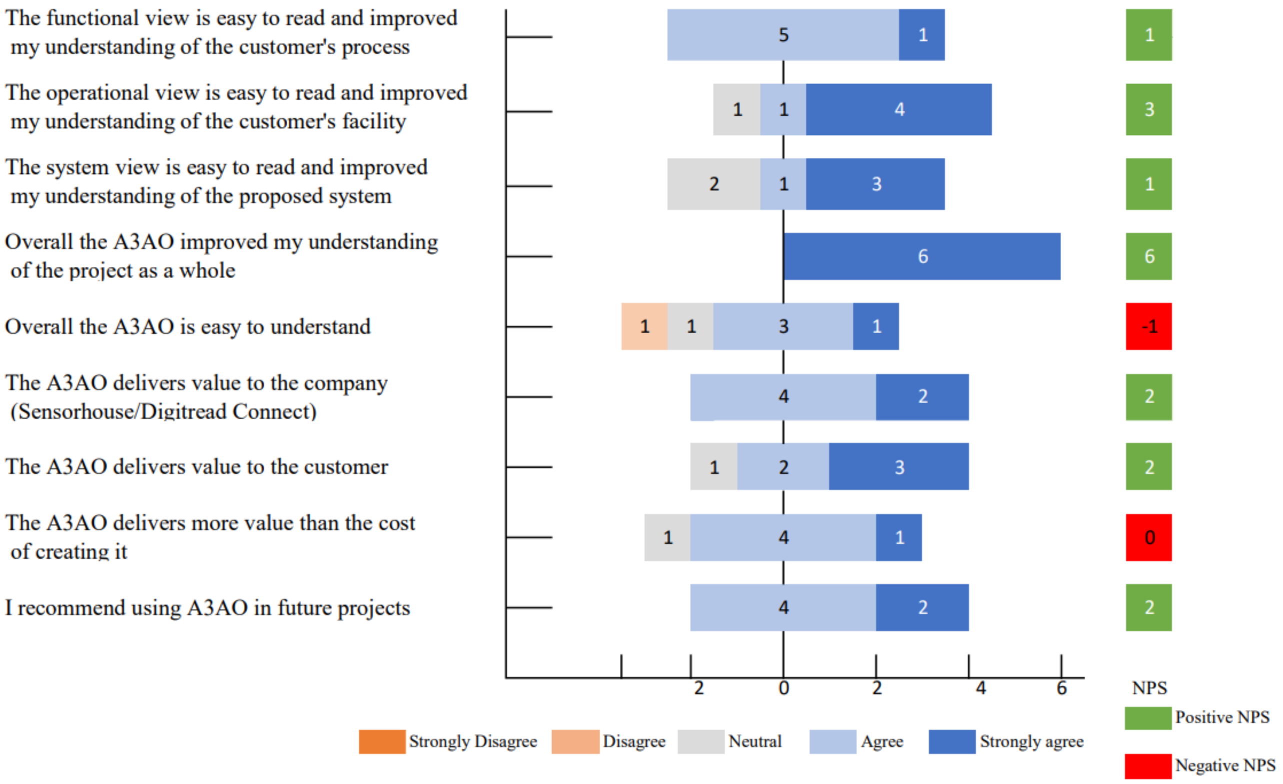


Figure 43 – Likert survey results

**Internal interviews.** The following section outlines the main findings of the interviews. We discussed the three main views in turn. The PoIs, Development and Installation plan, Maintenance assessment and cost are coalesced into "Other visual aids." The interview questions are found in Appendix A

**Functional view.** The participants generally liked the functional view, and everyone responded that it gives a clear picture of the customer's process. Several participants noted that the functional view combined with the PoIs communicated the project's scope and showed where the consultancy's effort would be. Regarding drawbacks, one participant was concerned that it could quickly become chaotic if the process had been more complex than the process in this case. Two participants noted that the functional view did not indicate the motivation behind the PoIs and was missing why and what was to be measured. One participant stated that it works very well on customers with a processing facility, such as this case, but was concerned with how it would work without a physical process, which is the case with many of the consultancy's customers. On future changes, one participant wanted multiple layers of functional views, with the ability to interactively dive deeper into subfunctions and sub-sub functions. Two participants wanted a color scheme and legend to ensure future projects use the same colors and to explain what the different colors meant.

**Operational view.** As with the functional view, the participants generally gave positive feedback on the operational view. A common trait was the closeness to the real-life factory, which helped to understand the scale of the system and factory. Multiple participants also noted that the view created a common ground between the consultancy and the customer, which makes it easier to detect errors or miscommunications. One participant indicated that the view let him know where we planned to install the sensors and the surrounding environment. Another participant noted that the view forms the groundwork for a GUI that usually is developed as part of most projects. Regarding concerns, almost all participants indicated that they did not intuitively understand the flow of the model and that it was hard to find a "red line" to follow. They noted that understanding it would take significant effort if somebody handed it to them without a walkthrough.

**Proposed system view.** The feedback on the proposed system view was also generally good. Most participants indicated that the view was easy to understand and gave a good overview of the components of the system. Multiple participants also noted that the model explained the data flow well. The ability to quickly and accurately understand what the consultancy would deliver was also a positive attribute. There was a distinct division between the participants regarding the detail level of the model. About half wanted less technical language by removing complex abbreviations and names, while the other half wanted more technical inputs, such as adding communication protocols between the system components.

**Other visual aids.** Regarding the rest of the views, the PoIs received the most positive feedback. Several participants indicated that the PoIs created a bridge between the various views, making it much easier to understand the entirety of the A3AO and the project. The maintenance assessment was also mentioned as a very positive addition since it communicates what the customer should expect regarding how much work it is to maintain the system. One participant noted that it should be more explicit who the maintenance falls on, if it is the customer's responsibility or the consultancy's. When it comes to the development and installation plan, a concern was that since we present the A3AO to the customer at a very early stage, there is a risk that it can create expectations that might be difficult to predict, especially regarding the installation and test phase.

**Overall main benefits.** All participants agreed that the A3AO gives a comprehensive overview of the system and project. Most participants mentioned the PoIs as a beneficial addition and that it connects the various views well. Most also noted that the A3AO conveys what the customer can expect to get out of the project and shows the plan for the project. Several participants said the customer can clearly see if the consultancy understands their process and facility. Furthermore, one participant noted that a significant benefit of using A3AOs was that it functions as a thought distillation for the team. Another participant said that by having the A3AO hanging on the wall, they (the developers) could use it as a map for discussions.

Some of the other benefits that came up were: Clear costs, easy to understand the process of both consultancy and customer, one-pagers are easy to read of non-executive employees of the customer, easy to understand the required maintenance, aligns the expectation between the consultancy and customer, and easy to see the cost breakdown.

**Overall main concerns.** There were a few concerns that most participants repeated, where the main concern was that the A3AO does not have an instinctual natural flow. Most participants said they would have struggled if they had received the A3AO without more information and that it required either the creator or someone familiar with the content to guide them through it the first time. Some said it would be possible to understand the content by themself, but it would require considerable effort and time. Multiple participants noted that the A3AO lacks the motivation behind the different decisions it shows. They wanted more information, such as why we chose the specific sensor and the thought process behind the choice. Because of this, several participants meant that it could not serve as a substitute for the regular documentation in a project, only as a supplement. There was also a concern about how it would work on larger projects, i.e., multi-site and more complex processes. Two participants also said that the A3AO forces a limit on the amount of information and that it will never have enough space.

**Presentation and feedback from the customer.** The A3AO was presented to the customer in a tender meeting and used as documentation in the proposal. The attendees were the customer’s CEO and CTO and two employees of Sensorhouse. The meeting lasted 60 minutes, and we spent most of the time going through the A3OA. The responses directly following the meeting were very positive from the customer side. Both participants enjoyed the presentation and said the document sufficiently described the project. During the presentation, the customer also quickly noticed a slight error in the operational view, where Sensorhouse had misunderstood an important conveyer belt aspect.

**Follow-up questionnaire.** The customer answered a follow-up question two weeks after the tender meeting (Appendix B). The feedback was generally positive, with primary concerns regarding the cost over value. The customer praises the ability to collect all critical information in one document and that the A3AO makes it easy to understand and evaluate the presented solution. On the negative side, they felt that the development of the A3AO was too expensive and wanted more functionality, such as the ability for the customer to edit and comment. They also noted that the models should use standardized illustrations to make them more efficient.

## Discussion

This study focuses on using A3AO as a tool for communication in tender processes, where we try to answer the primary research question: *"How can A3AO improve Sensorhouse's early validation and communication in the tender process?"*. This section discusses whether the A3AO is a viable solution. The results indicate that the A3AO functions as a tool for early validation and that it is possible to use A3AOs in tender processes. We collected data from internal and external sources, contributing to a varied perspective. The feedback was positive, with constructive criticism from both parties. The participants enjoy using A3AOs and report that it creates a good overview of projects. The A3AO proves to be beneficial regarding the ease of communication as it creates a common ground and aligns the users' viewpoints. The primary concern is the cost of making it and that it is hard to understand on its own or without a walkthrough from someone already familiar with the content.

Regarding cost, it is crucial to note that making A3AOs is a specific skill that takes time to master. This trait leads to an expectation that the development hours needed will decrease as the developer gets more familiar with and skillful in making them. We created all the graphical components used in the A3AO from scratch for this project. By building a standardized layout and a library of graphical elements, we expect the time needed to develop the A3AO will drop. Another important aspect is that some form of documentation needs to be created anyway, and it might not be a very large gap timewise between the two. Further comparisons need to be conducted to determine how the cost of making A3AOs stacks up against that of a traditional documentation process.

The next question is *"How can A3AOs be used to avoid miscommunication with customers?"*. We see that the A3AO forces a limit on the amount of information. The participants both praised and raised concerns about this topic, and we suspect their response is closely linked to their position in the consultancy and the respondent's personalities. We see that the developers and technical personnel tend to lean towards that it is a concern, while the employees with more customer contact praise it. On this topic, it is crucial to convey the mission of the A3AO. The A3AO is not supposed to be a technical schematic for developing a system. Its purpose is to be a tool for communication. Reducing the amount of information makes the models more manageable and not overwhelming for people without deep technical knowledge. Therefore, we perceive that the information limit imposed is a strength of the A3AO that reduces the chances of miscommunication between stakeholders in the project.

The study emphasizes that we created the basis for the functional and operational views during the customer workshop. This process requires the customer to actively participate in the modelling process, which reduces the risk of miscommunications and errors. After the digitalization process, we experienced that the customer detected a fault in the operational view, which could have led to unwanted results in the collection process of the wireless sensors. This proves that going through the A3AO together created a common viewpoint of the process, facility, involved systems and proposed systems and that the A3AO aligns the two world views, again reducing the risk of miscommunication.

The third question is *"What are the benefits of using A3AOs in workshops and tender processes?"*. Here we see an overwhelmingly positive attribute, where all participants in the Likert scale survey reported that the A3AO increased their understanding of the project as a whole. This attribute is vital to emphasize since it conveys an essential aspect of the early stages of a project. By quickly being able to get all developers (and other employees) to understand and get a feel of the overall goals, facilities, processes and challenges in a project, the risk of errors in the tender process drops since it will become easier for the developers to give feedback on technical aspects, hourly estimates, and other costs.

The last question is, *" What may be the challenges with the A3AO modelling format for tender processes?"*. The first challenge is, again, cost. Creating the A3AOs will always have a cost factor alongside it since it is more demanding than writing something down on a piece of paper. The consultancy must present the cost to the customer, who might not want to prioritize it even though it provides value. Next, it is an untraditional way of working, which might be harder to sell to new customers who are used to a more traditional process of doing needs elicitation. Because of the untraditional nature of the A3AO, it also has a relatively steep learning curve. The creator needs to learn the basics of the technique and become familiar with creating graphical components and visual aids. This process is a distinct skill that is possible to argue lies closer to a designer than an engineering position. It is also not necessarily something most engineers want to spend time doing, which must be considered when deciding whether or not to implement the method.

The last challenge we see is that the A3AO used in this study only functions as a supplement to the traditional documentation process and not a substitute. Because of the limitation of the information, the motivation behind all the presented decisions, systems and components is not possible to incorporate, which is a significant drawback. The A3AO functions as a summary that can be presented to the customer, but if the customer wants more information, it must be provided in regular documentation. This means that often both approaches must be created simultaneously, adding to the development time.

## Conclusion

This study introduces a different way of working regarding consultancy processes in the IoT field. We discovered a pain regarding communication in the consultancy and investigated whether a method within SE literature existed. Borches' A3AO was identified as a possible solution. We took the primary idea behind the A3AO and tailored it for the consultancy's workflow before testing it in a real-life industry case.

During the study, we received feedback from both internal and external sources. The combination of observations, interviews, the Likert survey, and the follow-up questionnaire forms a rich data collection from many different perspectives and backgrounds. The results indicate that the participants find the A3AO beneficial for the consultancy and customer, with concerns regarding cost and complexity. In general, our findings show that the A3AO successfully bridges the gap between stakeholders in early validation processes. We see that developing A3AOs is a distinct skill that needs practice and that it will likely become more beneficial by cutting cost and development time as we become more familiar with it and our modelling skill increases. The A3AO still needs to be perfected in many ways, but it already provides good value for the consultancy. After the study, the consultancy decided to implement and use A3AOs in future projects.

Lastly, we want to encourage all readers to test using A3AOs themself. It is the process of experimentation that drives the advancement of Systems Engineering, and by leaping into the unknown, we take the most important step, which is always the next one. We learn and become stronger along the journey, not by looking at the destinations.

## Limitations and Future Research

**Limitations**. We gathered responses from various people, both internally and externally. The interviews, the Likert survey, and the follow-up questionnaire, provided many perspectives, thoughts, improvements, and constructive criticism. Ideally, there should have been more participants in the surveys, but to involve more participants meant using external sources not participating in the case, which would not provide the same genuineness as the responses shown in the study. Because of the small sample size, the results shown cannot yet be used as a basis for generalization.

**Future research.** One of the main concerns of using A3AOs we found was the cost aspect. We suspect that much of the documentation would have to be created anyway and that the cost of developing an A3AO is likely higher, but not substantially. We recommend further research into comparing an A3AO process and a normal documentation process. This research would create a more precise cost picture which can potentially be very beneficial to a broader adaptation of the technique.

Another significant concern discovered was that the participants often felt like the A3AO laced an instinctual flow. Therefore, we would like to investigate how to incorporate this flow into the document. The reader should be able to take up a new A3AO and intrinsically understand how they should read it, just like they know how to read a new book. The last concern we recommend investigating is more complex, especially multi-site projects. It isn't easy to know how to proceed here; maybe several A3AOs in a hierarchical order must be created. This topic is fascinating and something that needs further research.

For this industry case, we strongly recommended scheduling a secondary validation after the project delivery is complete to discuss the results, experiences, and possible changes to improve future projects.

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## Biography

**Eirik Hidle**. Eirik received his bachelor's in electronics from the University of South-East Norway (USN) in 2020. Between 2020-2023 he studied Systems Engineering at USN, where he graduated with his master's degree in 2023. During his education, he worked part-time as a project engineer and technology advisor for Sensorhouse.

**Marianne Kjørstad** received the B.S. degree in mechanical engineering from the University of South-Eastern Norway (USN) in Kongsberg, in 2003, the M.S. degree in product design and manufacturing from the Norwegian University of Science and Technology (NTNU) in Trondheim, in 2005, and the Ph. D. degree in Systems Engineering from USN, in 2022. She is fully employed as a Systems Architect in Kongsberg Maritime combined with a part-time position as Associate Professor II in Systems Engineering at USN.

Dr. Kjørstad has 19 years of experience from the maritime industry and been involved in research, design, development, integration, testing, and commissioning of high-tech complex system. She is an experienced Systems Architect primarily focusing on applied Systems Engineering in design of innovative high-tech systems to the ocean space. Her research interests include Systems Engineering and Systems Architecting combined with design theory and creative practices to bring forward innovations.

# Appendix A – Internal Interview Guide

Interview guide

Functional View

Benefits:

Concerns:

Recommended changes:

Quote:

Operational View

Benefits:

Concerns:

Recommended changes:

Quote:

System View

Benefits:

Concerns:

Recommended changes:

Quote:

Other visual aids

Benefits:

Concerns:

Recommended changes:

Quote:

Do you have any comments on the topic of value? In what way does it provide / not provide value?

Please list three benefits of using A3AO:

Please list three concerns of using A3AO

# Appendix B – Jordpro Survey Results

**Jordpro survey for Master thesis by Eirik Hidle**

A3 Architectural Overviews in early validation – a case study in an IoT consultancy

The functional view sufficiently explained our processes in regard to this specific project.

| | | | | | |
|---|---|---|---|---|---|
| Strongly disagree | Disagree | Neutral | **Agree** | Strongly agree | NA/Don't know |

The operational view sufficiently explained our facility in regard to this specific project.

| | | | | | |
|---|---|---|---|---|---|
| Strongly disagree | Disagree | Neutral | **Agree** | Strongly agree | NA/Don't know |

The system view sufficiently explained the proposed system in regard to this specific project.

| | | | | | |
|---|---|---|---|---|---|
| Strongly disagree | Disagree | **Neutral** | Agree | Strongly agree | NA/Don't know |

Overall the A3AO sufficiently explained the project as a whole:

| | | | | | |
|---|---|---|---|---|---|
| Strongly disagree | Disagree | Neutral | **Agree** | Strongly agree | NA/Don't know |

Overall the A3AO is easy to understand:

| | | | | | |
|---|---|---|---|---|---|
| Strongly disagree | Disagree | Neutral | **Agree** | Strongly agree | NA/Don't know |

The A3AO delivers value to the project:

| | | | | | |
|---|---|---|---|---|---|
| Strongly disagree | Disagree | Neutral | **Agree** | Strongly agree | NA/Don't know |

The A3AO delivers more value than the cost of creating it:
(After the system development is complete, it is estimated that we use 8 hours to make the graphical components used in the A3AO)

| | | | | | |
|---|---|---|---|---|---|
| Strongly disagree | **Disagree** | Neutral | Agree | Strongly agree | NA/Don't know |

I recommend Sensorhouse to use A3AO in future projects:

| | | | | | |
|---|---|---|---|---|---|
| Strongly disagree | Disagree | **Neutral** | Agree | Strongly agree | NA/Don't know |

Please list three benefits of using A3AOs:

All in one place for customer, one document for all is convenient and easy to use

Setting up different approaches/ways of presenting with the use of points of interest on all makes it easier to understand and evaluate the solution

Please list three concerns of using A3AOs:

Time consuming, too high cost on graphics

Would recommend to consider more standardized illustraions (e.g. P&ID, flowcharts etc) for efficiency reasons

More functionality would be nice; interaction by enabling customer to edit, comment etc

Optional: Do you have any comments on the topic of value? In what way does it provide / not provide value?

Our project has a small budget and limited scope. As said above: Important that actual results on the core topic (e.g. sensors introduced and delivering usable information) are prioritized.

One value delivery is to make sure that we (customer and supplier) are aligned on scope, details in project and execution. Important to use it as an actual tool for interaction/dialogue.

So in general positive, but needs to be efficient ☺

# Appendix C - Full-Size A3AO

On the next page (A3 size).

# Jordpro A3 Architectural Overview

A3AO information
Creator: Eirik Hidle
Revision: 1
Date: 03.03.23

## Legend

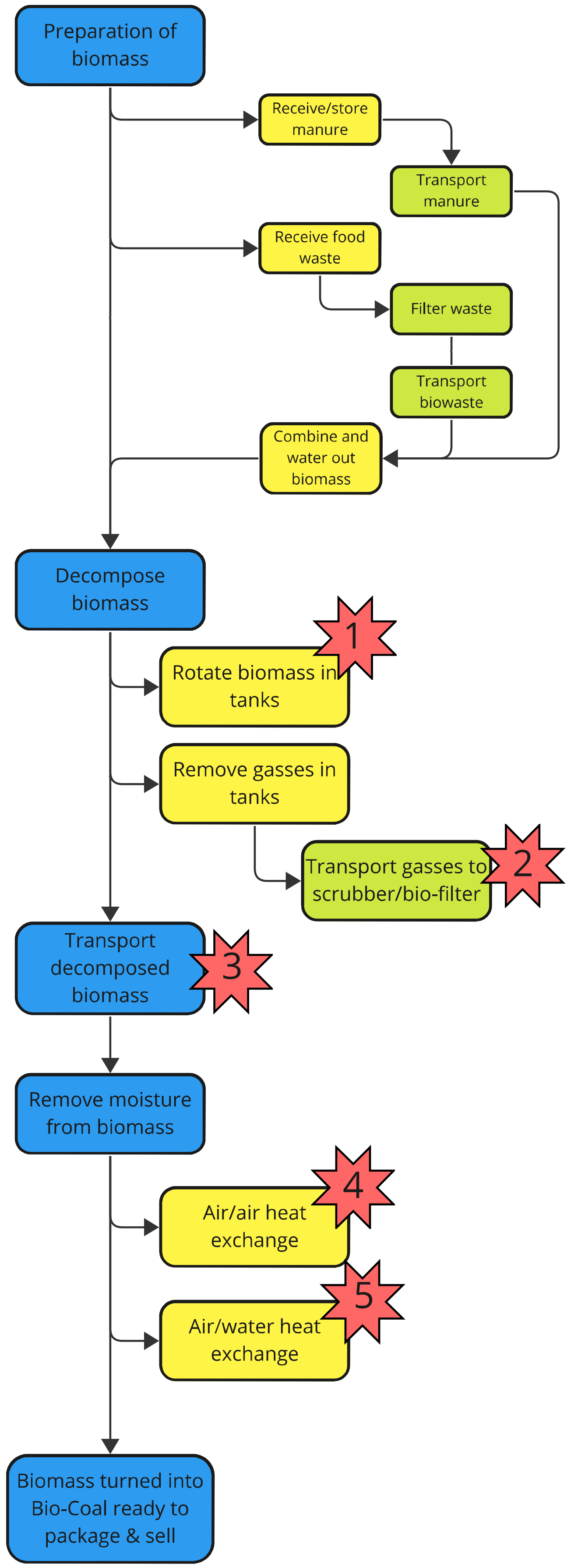
Point of interest

Sensor

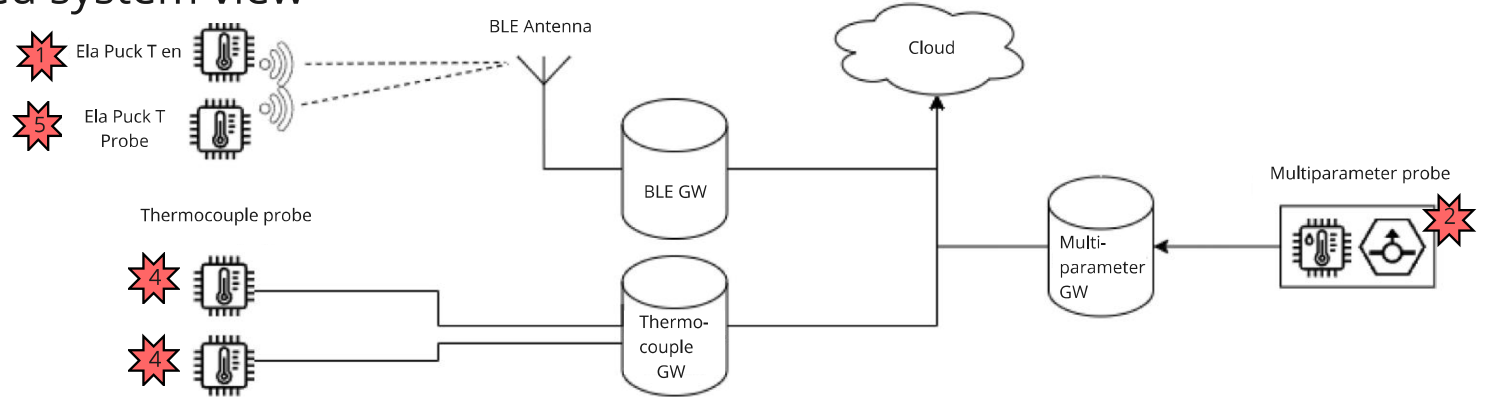
## Abbreviations

GW - Gateway
BLE - Bluetooth low energy
MP - Multiparameter

## Functional view

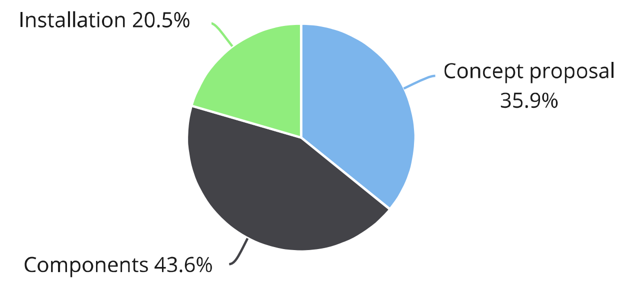


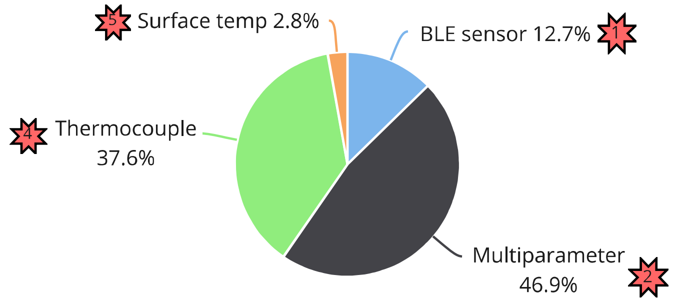

## Proposed system view




## Cost

| Nr | Name | Point of interest | Amount | Price per unit NOK | Allocation NOK | Per cent of total cost (%) |
|---|---|---|---|---|---|---|
| 1 | Concept proposal | | 1 | | 35 000 | 35.9% |
| 2 | Blue puck T EN | 1 | 6 | 400 | 2 400 | 43.6% |
| 3 | Thermocoupe probe | 4 | 8 | 1000 | 8 000 | |
| 4 | Blue puck T Probe | 5 | 2 | 600 | 1 200 | |
| 5 | Moxa ioLogik E1262 | 4 | 1 | 8000 | 8 000 | |
| 6 | TRB RUTX10 | 1, 5 | 1 | 3000 | 3 000 | |
| 7 | Moxa ioLogik E1240 | 2 | 1 | 8000 | 8 000 | |
| 8 | Multiparameter probe | 2 | 4 | 3000 | 12 000 | |
| 9 | Installation & Test | | 1 | | 20 000 | 20.5% |
| 10 | **Total** | | | | 97 600 | |




## Points of Interest

**1** Parameter: Biomass temperature.
Sensor submerged into biomass to log temperature during the decomposition cycle.
req. for documentation to Food Safety Auth.
Cycle time ~2 weeks, temperature ~85 °C. Corrosive and wet environment. Tank made primarily of steel. Sensor collected in PoI 3.

**2** Parameter: Gas temperature, humidity and flow-rate (pressure).
Sensor probe(s) installed in pipe after exhaust fans and before bio-filter/scrubber split to monitor and alert on operational status. Temperature ~50°C, highly corrosive and humid gasses.

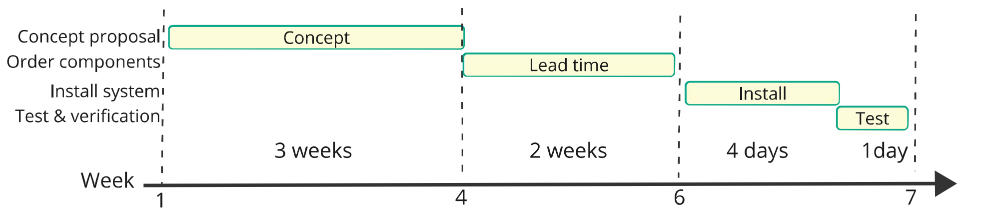
**3** Sensor from PoI 1 collected along transport. Person collects sensor from grate and reintroduce it in composte tank.

**4** Parameter: Air temperature
Sensor probe(s) installed in air duct to gain insight into heat loss in pipes and operational status.
Temperature ~500 °C. Low humidity non-corrosive gasses.

**5** Parameter: Surface temperature
Sensor probe(s) installed on surface of water pipe.
Temperature 100 °C.

## Development and installation plan

Time for installation, test & verification is based on one technician. Time can be shortened if more personnel is used.




## Maintenance assessment

| 1 5 | 2 | 4 |
|---|---|---|
| Check/replace battery | Inspect & Recalibrate | Recalibrate |
| 1 y | 1 y | 1 y |
| Expected End of life | Expected End of life | Expected End of life |
| 2 y | 5 y | >5 y |

Other equipment such as gateways, antenna & electrical wiring are expected to last longer than 5 years. All equipment can be disposed in electrical waste when replacements/upgrades/ end-of-life arises

## Operational view