Using A3 Architecture Overviews as an educational tool

Educating new artists in Systems Architecting

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Abstract

To successfully develop a system, a solid understanding of its architecture by stakeholders involved in the development of the system is key. This process is supported by System Architects, who have a profession that is often regarded as experience based. However, we argue that it is important to familiarize students with the concept of System Architecting, so that they are at least receptive of the nuances involved and potentially can continue a pathway of development towards such a role. In this paper we explore the potential use of A3 Architecture Overviews (A3AO) as an educational tool to support familiarization with Systems Engineering and Systems Architecting. The A3AO has been developed as a supportive tool to communicate a system's architecture. It uses diagrams to model and visualize a system with different views and is intended to be printed on a physical A3 paper. It serves as a reference for, and facilitator of design discussions. Skills envisioned to be developed while using an A3AO include strict selection and visualization of information, two critical competencies to handle systems' complexity. The A3AOs have been applied in a course on Systems Engineering at an applied University in The Netherlands and were part of the assessed deliverables. The relative free-form nature of the A3AO posed students with various dilemmas in their use, but also provided the opportunity for guided development on the envisioned competencies. We conclude that more research is required to further formalize this guided development, but we also experience that the A3AO has the potential to support systems engineering and systems architecting practices in education.

1. Introduction

In the past decades, society and its supporting systems have been transitioning to an increasingly connected and digital world. This pace is only accelerating. For engineers or other developers, this means that more and more, they must design their products considering the wider context of that product, and not consider them as products but as systems. To handle complexity, an engineer should scope development towards a specific system-of-interest. However, scoping already implies that the system-of-interest is part of a larger system. Therefore, an engineer should consider both the influence of the wider context on the system-of-interest, as well as the impact of the system-of-interest on its context.

The domain of Systems Engineering offers processes, tools and ways of thinking (Bonnema, Veenvliet, and Broenink 2016) that support the development of such systems. The more strategic and holistic side of the Systems Engineering approach is often called Systems

Architecting. In this context, the architecting approach has been referred to as an art (Maier and Rechtin 2009). The earlier described societal need for systemic solutions prompts an increasing need for professionals that can address this need. Ultimately, this begs the question how to educate new artists in Systems Architecting. We explore this question in the context of a Master program at the HU University of Applied Sciences Utrecht in the Netherlands.

The paper aims to answer the posed question as follows. Firstly, by discussing the background of systems architecting and their education in section 2. Secondly, by introducing a tool – A3 Architecture Overviews (A3AOs) that may contribute to this education in section 3. An exploratory case study utilizing the A3AOs is presented in section 4. Finally, the outcomes of the case study are discussed in section 5. An outlook for future work is presented in section 6.

2. Teaching Systems Architecting

This section discusses key aspects of Systems Architecting in an educational context. Already at the early days of Systems Engineering, the comparison to Architecture was identified. Bode (1967) is paraphrased by SEBOK in a brief history on Systems Engineering (SEBOK 2023a):

> *"…the systems engineer resembles an architect, … Like architecture, systems engineering is in some ways an art as well as a branch of engineering. Thus, aesthetic criteria are appropriate for it also. For example, such essentially aesthetic ideas as balance, proportion, proper relation of means to ends, and economy of means are all relevant in a systems-engineering discussion. Many of these ideas develop best through experience. They are among the reasons why an exact definition of systems engineering is so elusive."*

Within the ISO/IEC/IEEE 42010 (ISO/IEC/IEEE 2011), the following definition is offered for a system architecture:

> *"fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution"*

The ISO/IEC/IEEE 42010 definition shares some overlap with the definition in SEBOK (SEBOK 2023c). In the above views on Systems Architecting we see terms such as "global", "high-level structure" and "fundamental concepts" that are derived from the "properties", "relationships" and "elements" of a system in such a way that "balance" and "proportion" are maintained. Going forward in this section we will discuss the core qualities expected from a systems architect and how to address this in an educational context.

2.1. Core Competencies of a Systems Architect

In educating systems architecting, the students should be familiar with the way of working and competences of a systems engineer. One can take inspiration for this from for instance (Bonnema, Lutters-Weustink, and van Houten 2005; Bonnema, Lutters-Weustink, and Jauregui-Becker 2016) and (Muller and Bonnema 2013). Based on the definitions offered above, and for example the work of (Maier and Rechtin 2009) and (Muller 2011), we can derive additional relevant activities central to the System Architecting process, and from those derive relevant competencies for a systems architect.

In principle, a System Architect has a visionary and strategic role with a systems' development, or even across the development of multiple systems (Muller 2011). To support this role, we would like to highlight two competencies. In this, we acknowledge that we are by no means exhaustive or complete in the competencies we present.

The first competence to highlight relates to finding the “fundamental” aspects of a system. This means that given the topic at hand, a System Architect should excel at critical information selection, or to *be able to capture the essence of a system*. This includes interacting with a wide variety of stakeholders, being able to ask the right questions and scan information quickly. It also involves being able to reason in a more functional manner, which allows one to focus on the purpose of a system.

Secondly, the results are then to be communicated across stakeholders (which can occur simultaneously with the capturing process). To support this, a System Architect should *be able to visualize and communicate the essence of a system* appropriately. Multiple approaches can be used here, for example facilitating a common language (e.g. through SySML) is one, but it can also be done through less formal means (Muller 2011). The end goal is to facilitate a shared view on the system.

In principle, (Maier and Rechtin 2009, p274) state in their guidance on curriculum design that Systems Architecting is primarily inductive and heuristic based, whereas other engineering course are more deductive. In this, there is another competence to be found, which is to act on heuristics (Maier and Rechtin 2009). We argue that this competence exemplifies why System Architecting is often regarded as an experience-based profession.

The question then becomes where to start with junior “product” engineers that are novices in system development. In our view, Systems Engineering and Architecting education gives counterweight to the usual engineering educational flow of focussing on ever more precise details to ever more depth. If one wants to educate future systems engineers and architects, the first step is to make students aware of the profession of a Systems Engineer/Architect (SE/A). Some students will want to learn more, and potentially develop into full systems engineers or architects. The two competencies “be able to capture the essence of a system” and “be able to visualize and communicate the essence of a system” we presented are, in our view, ideal starting points for students to exercise and experiment with.

3. A3 Architecture Overviews

This section presents the A3 Architecture Overview and will discuss its conception and why we consider this a potentially natural fit in education.

3.1. A short history

A3AOs were conceived as the result of the work of (Borches 2010). Borches was looking for a way to support evolvability in high-tech systems. After an extensive exploration he concluded that the problem was not so much the inability of engineers to estimate the impact of change, but the lack of shared understanding of the system and its architecture. He therefore developed a way to reverse engineer (often implicit) architectural information of a system to support product evolution. This resulted in the A3 Architecture Overview, as depicted in Figure 1. As stated by Borches, its design is based on experiences with existing models (including e.g. SySML), tools, and human and organizational factors. The aim is not to be complete, formal, or executable. Instead, the aim is to support effective communication of architecture knowledge. This is done by using non-formal models to discuss a specific (aspect) of a system in interlinked functional, physical and quantification views, supported by visual aids and other views where appropriate. Furthermore, the visuals provide links between the information in the different views, e.g. by indicating which main concerns or requirements apply to which aspects in the specific views. These views are captured on the model side, whereas the summary side provides supporting rationale and further context.

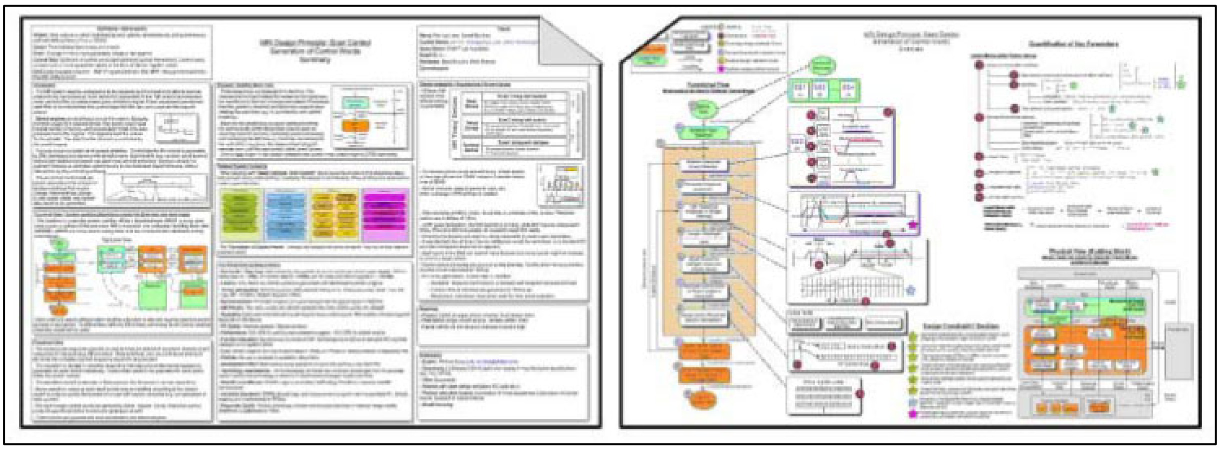

Figure 1 – A3 Architecture Overview example – Left: A3 Summary, Right: A3 Model (Borches 2010) *(rendered unreadable for confidentiality reasons).*

The A3AOs have been implemented in various industries such as healthcare and the oil and gas industry (Kooistra, Bonnema, and Skowronek 2012; Singh and Muller 2013; Wiulsrød, Muller, and Pennotti 2011), and different methodological approaches have also been explored[1]. These approaches range from supporting new product development (Hooft et al. 2020) introducing interactivity (Brussel and Bonnema 2015) and incorporating A3AOs in the communication of simulation studies (Haveman and Bonnema 2016).

Concluding, an A3AO captures interconnected key pieces of information from different viewpoints on a single piece of A3 paper to present and discuss the essence of a system on a specific topic. Due to its paper-based nature, the A3AO is particularly suited for traditional face-to-face meetings and for personal reference.

3.2. The A3AO – a natural fit in education?

The A3AO is (as is the case for systems engineering and architecting in general) directed towards the whole, instead of to the details. It can therefore be used as facilitation medium in first contact with the profession of an SE/A. Because of the hard limitations of (two sides of) an A3 paper, students are forced to decide on the relevance for the system design of every piece of information. At the same time, the format of the A3AO with its three main views, and headings on the text side, helps students in this effort. Already the exercise of making a functional view in addition to the mostly preferred physical view helps students to explore both the solution and the problem domain (Bonnema, Veenvliet, and Broenink 2016). Identifying and quantifying key parameters (also called system aspects, key drivers) is a second important exercise to understand the job of an SE/A.

From a didactic perspective, one could paraphrase the A3AO as easy to learn but hard to master. The iterative process of developing an A3AO (Borches 2010) supports a process of refinement

[1] For more information, see also http://www.a3ao.eu/

and continuous learning. We also pose that the visual style of the A3AO can be regarded as more attractive to prospective students compared to alternatives.

Based on the above, we believe the A3AOs are well suited in an educational setting. In the remainder of the paper, we discuss the application of A3AOs in education and explore the question "Can the A3AO method serve as a supportive educational tool to introduce students to systems architecting?"

4. Exploratory Case Study

In this section we will discuss an exploratory case study where the A3AO is used in an educational setting. We refer to this case study as exploratory since it was not designed as an educational experiment upfront. Nonetheless, we report on the designed educational approach, and we reflect on our and the students' experiences in this course.

4.1. Setting

Our case study is situated in an educational programme at the HU University of Applied Sciences Utrecht in the Netherlands. The case study was executed in the master's program Next Level Engineering (MNLE). The MNLE program is a 1 year, 60EC, full-time program aimed at engineers with a bachelor's degree. The program widens the scope of the often still mono-disciplinary engineers with a systems perspective, data science techniques and offers perspectives on organizational change. A Systems Engineering course (5EC) in which this case study is executed runs in the first quartile of the curriculum. Adjacent to this course, the students also work on an Interdisciplinary Project. The Systems Engineering course makes use of that project to apply SE techniques and methods directly to the running cases in the project.

The Systems Engineering course has two intended learning outcomes, of which one is specifically linked to the use of A3AOs. This has the following definition:

> *After completing the course, the student demonstrates the ability to analyse, design and improve complex systems, components and / or processes to meet the specified needs with respect to realistic constraints from an economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability point of view.*

Translated shortly we communicate this as "The student has hands-on experience with Systems Engineering and is comfortable in applying it in a design process". To structure the course in a few thematic sessions, the course was designed around three phases or focus areas, overlayed on the Vee-model, as can be seen in Figure 2

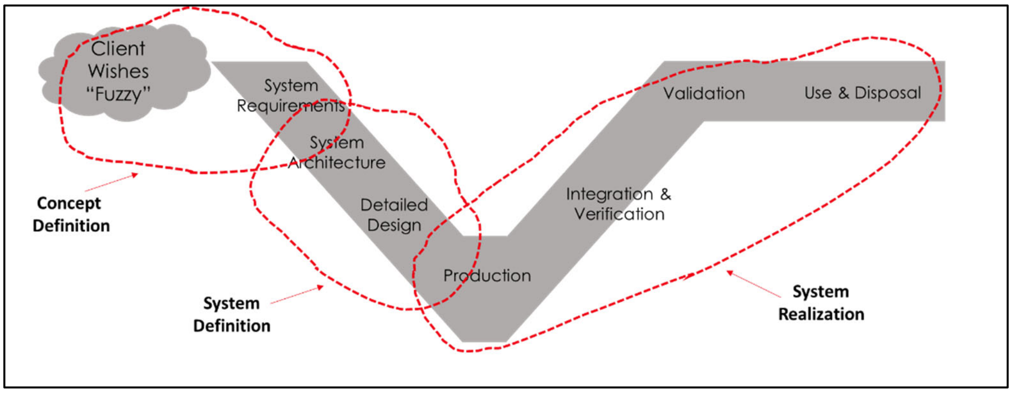

Figure 2 – Focus Areas (Concept Definition, System Definition, System Realization) within the Systems Engineering course

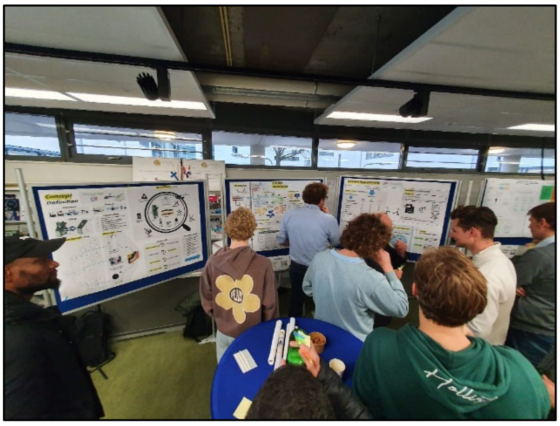

Figure 3 – Poster Market with enlarged A3AOs

The specific assignment that was asked to the students was to create three SE posters[2] based on the A3AO style, one for each focus area. These posters, or A3AOs, were also required to facilitate a design discussion. The content of the posters was linked to the projects the students were executing in the parallel course "Interdisciplinary Projects". A full description of the assignment can be found in Appendix I. The final assessment for this assignment was a group interview in a meeting setting – the examiners and students sat around a table and discussed the printed A3AOs in the middle of the table. The assessment rubric used can be found in Appendix II. Furthermore, a set of questions was prepared for the examiners and can be found in Appendix III –these questions focus on the use of the tool, rather than on the presented results in the A3AOs. It should be noted that at that point in time, the running projects were only halfway through – the projects themselves last one semester.

To conclude the course, the A3AOs were printed enlarged and demonstrated to a wide audience (of students in other programmes, teachers, project clients and others) in an informal poster market setting, see Figure 3. This last activity was not part of a formal assessment for the course results.

4.2. Results

Three groups of five or six students executed the assignment. The groups were working on three separate projects in the healthcare and energy domains. The educational and cultural background of the students was diverse (but limited to the engineering domain). Each group of students delivered a set of three A3AOs as requested in the assignment, one for each focus area (see Figure 2). We report on three aspects of the study, being the process, the results and the outcomes of an evaluation.

The assignment was introduced in detail halfway through the course and from that point a weekly returning topic in tutorials where we would discuss draft versions with the students. In this, students were logically starting with a blank canvas and filling it step-by-step. We encouraged students to utilize the A3AOs in design discussions with stakeholders in their projects, but we also observed that students seemingly lacked enthusiasm or incentives to do so.

[2] We made a subjective choice to present the concept to student as posters, in this paper we aim to consistently use A3AOs if applicable to refer to the created artifacts.

Towards the end of the course, the A3AOs were finalized by all groups and submitted for the assessment. Three of the results are shared in Figure 4, Figure 5 and Figure 6. In the assessment, the examiners (two of the authors) focused on the model sides and discussed with the groups what each model side brought or could bring to the design process. The rationale on the summary side of the A3AO was regarded by the examiners mainly as preparatory work by students for the discussions in the assessment. In the end all groups passed the course. For each group, we present a few of our remarks

- Group 1, this group managed to provide the different views as requested but lacked a clear scope in their A3AOs. In Figure 4, their “concept definition” A3AO is depicted. It aims to present different kinds of concepts for interactivity and links this choice across different views. After discussion in the examination, this poster was assessed to lack some crucial details, so in that sense, the overview was incomplete. A further observation is that the visual style used for the context diagram is perhaps too ambiguous, which is an inherent risk of using an informal modelling approach.
- Group 2, this group focused very heavily on a graphical and storyline approach for their A3AOs. In this, they presented a clear story but lost some of the Systems Engineering approach. An example can be seen in Figure 5 which discussed the “system definition”. Here a functional block diagram, an N2 diagram and requirements can be recognized. However, the remaining content is a bit unstructured – other tools could have been applied.
- Group 3, this final group admirably struck a nice balance between "SE-language" and an attractive visual style, as shown in Figure 6. The wall visual itself is a nice touch since the project was about house renovations. The system interactions might be hard to read but were an admirable effort to transform an N2 diagram into a more compact style.

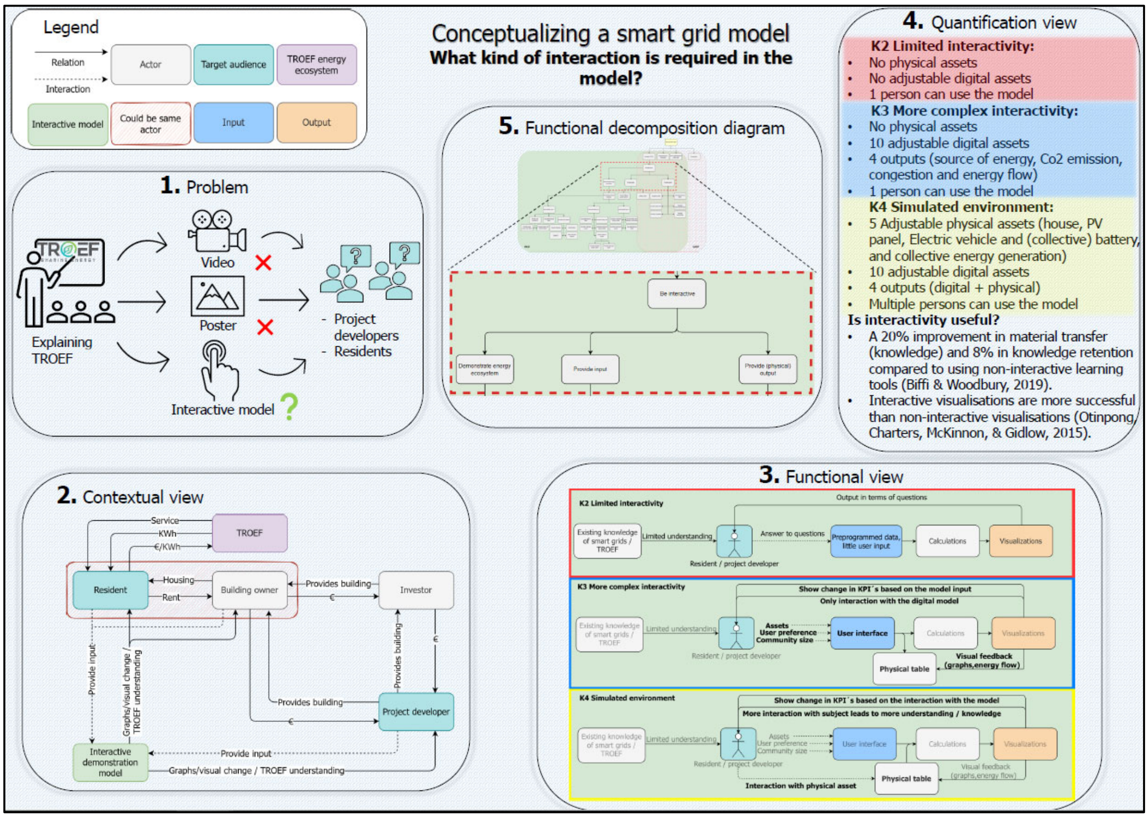

Figure 4 – Concept Definition A3AO Model Side of Group 1

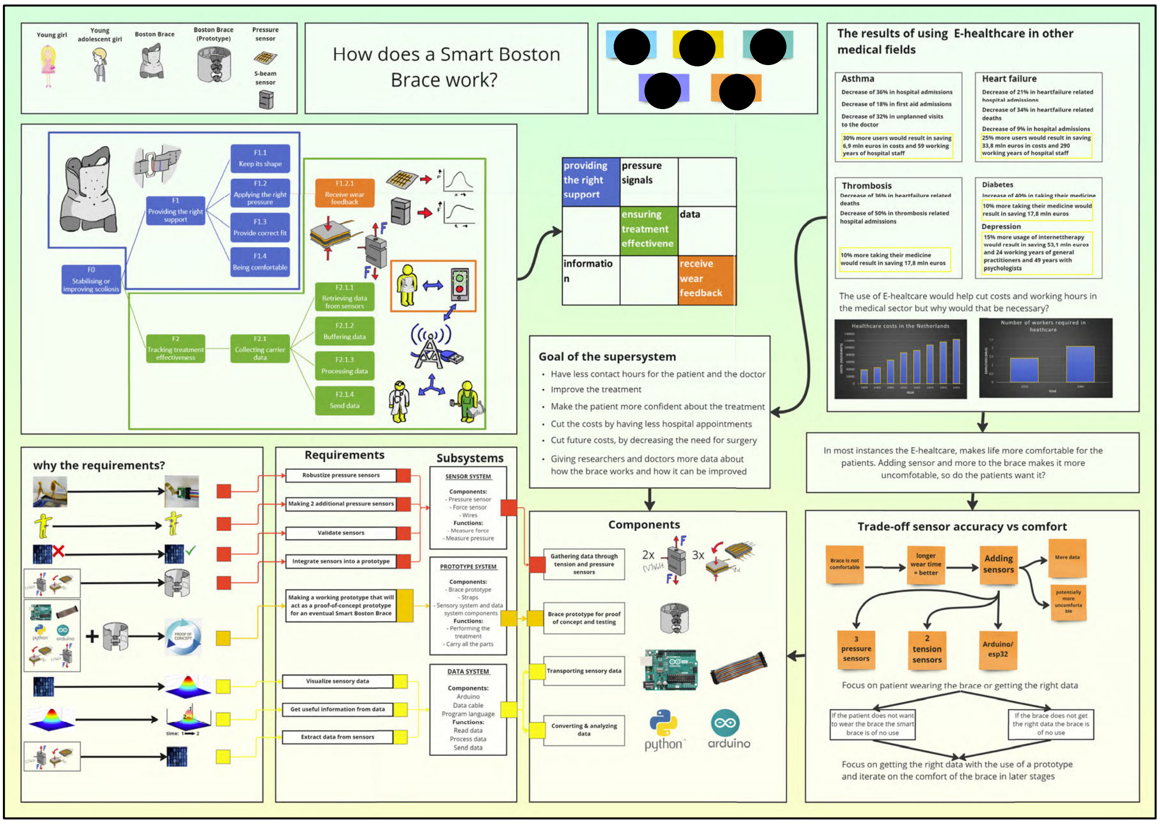

Figure 5 – System Definition A3AO Model Side of Group 2 (names of group members are hidden with black dots)

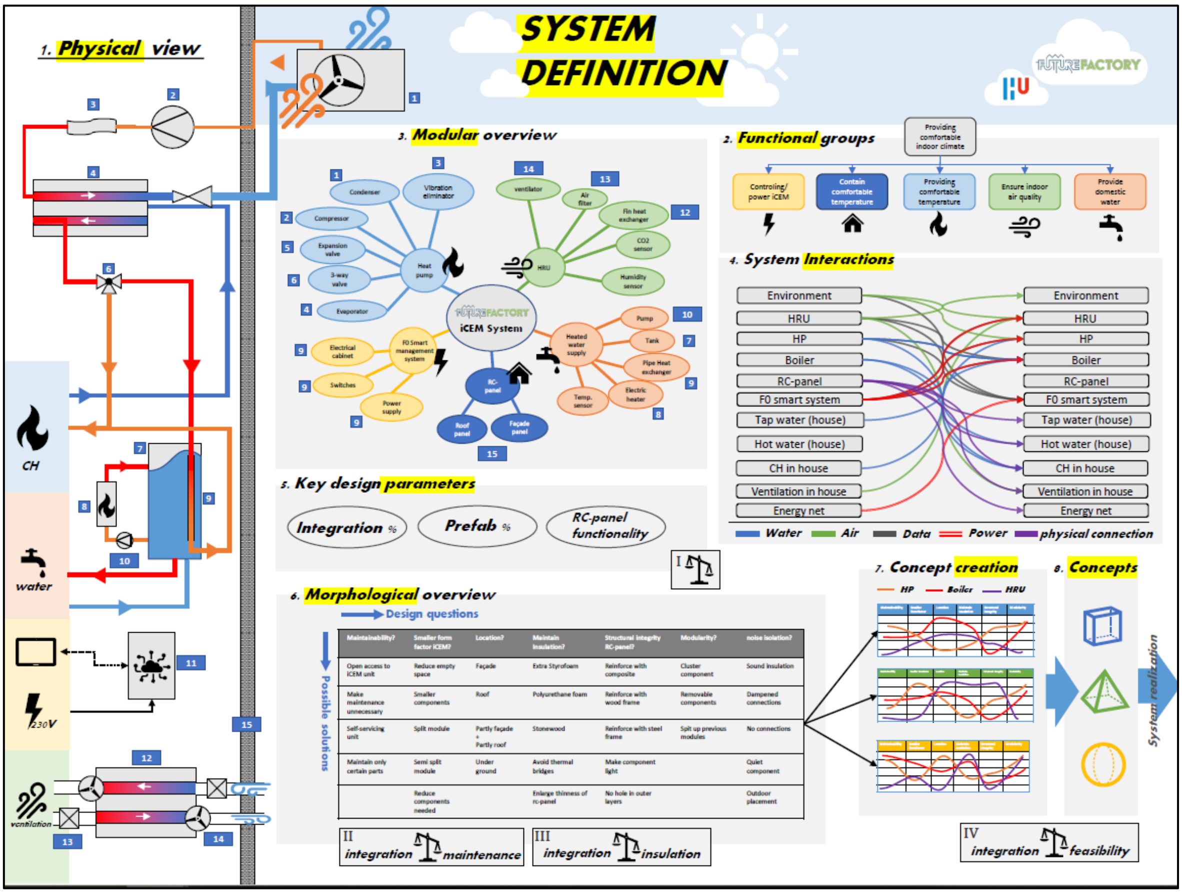

Figure 6 – System Definition A3AO Model Side of Group 3

The course and application of the A3AOs were evaluated by discussions between students and teaching team, a survey and two in-depth interviews. All these evaluations were not specifically focused on the A3AOs but when analysed, provide a few points of feedback.

- We start with seemingly the worst feedback at face value. In one course evaluation a student stated "I though the example poster was very ugly. If I would encounter this at a company, I could not take this company seriously".
- More feedback was offered by the same student, which was also supported by other students in discussions. This feedback centred on the fact that "the posters were a lot of work for information that was already known".
- The two in-depth interviews revealed the working process for two of the groups. In a project setting students will naturally divide the work between them. This had as consequence that in those groups the posters had one main author with other students in a supporting role, sometimes very limited.

5. Discussion

In this section we reflect on our own experiences and particularly the final points of feedback presented in the case study results.

In our view, the greatest strength of the A3AO is also its greatest weakness: anything goes. The tool can be used for many goals, many audiences (internal, external) and in many development phases or contexts. This apparent Swiss-army knife quality is both an opportunity and a threat. Overall, we have perceived the A3AO approach as beneficial as it allowed us to have discussions on our suggested competences, capturing and communicating the essence of a system. However, these guided discussions were lacking during the course and mainly surfaced at the "wrong" time, at the assessment.

Reflecting on student feedback, without focusing too deeply on a single piece of feedback, it seems critical to continue reflecting on the offered statements. The initial reaction to the student feedback of "a lot of work for information that was already known" might be that if it was already known, why is then a lot of work? This can mean several things that require more research. It might mean that students did not yet know everything, and at least did not know which parts of the information that they knew was relevant enough for the A3AO. It might also mean that our engineering students struggle with the visual style of the A3AO. Or it might just mean that benefits of creating an A3AO are missing or not made visible well enough.

6. Future Work

In the coming years, the authors will continue to develop the educational programs that they are involved in. Our aim is to continue to work with visual approaches that support an initial transition of mono-disciplinary engineers to systems engineers. Most importantly, we aim to educate a wide variety of bachelor and master students in systems thinking, a crucial 21st century skill.

In this context, we will continue to explore the usage of A3AOs. Based on our learnings in the case study presented in section 4, we aim to introduce the concept of A3AOs right at the start of the program instead of halfway through in the next educational year. Furthermore, we will only require a single A3AOs to be used (though more are allowed, for instance for certain aspects or subsystems), to support a more active and focused use of the tool in the development process of the case the students are working on. In that sense, we aim to address some of the concerns raised by the students by presenting the A3AO as a tool that supports along the way instead of being an end-of-the-line reporting tool. An interesting avenue is to focus on assessing the use and evolution of the A3AO and request a submission of the different versions in a portfolio, instead of only the final version.

In the continuation of research on the use of A3AOs in education, we suggest exploring and consolidating a typology for the use of A3AOs. Is it possible to formulate guidelines to utilizes A3AOs in different contexts? Is it possible to give practical implementation examples? Example questions that should guide potentials users to a supportive description could be the following. Are you supporting a development project? In which phase? Are you supporting a formal decision process? Are you starting a discussion? Are you informing an audience? Do you want to co-design a solution? Do you want to validate your solution? Do you want to trigger stakeholders for input? Do you want to educate stakeholders/employees?

The outcomes of the case study show that A3AOs have a potential role in kick-starting systems engineering and architecting competencies. The questions posed above show that there is still work required to get a better understanding of when, where, and how A3AOs are most relevant.

7. Acknowledgements

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Appendix I – “SE Posters” Description

- **Format**
  - Group composition: The assessment is executed in the same group as the Interdisciplinary Project Group
  - Deliverable: 3 posters in A3 Architecture Overview style
- **Guidance**
  - Create three posters, which together give a good overview of your Interdisciplinary Project, with the following scope:
    - **Poster 1 – Concept Definition**
      - Explain the problem scope and chosen concept – avoid detailing the solution. Include at least a functional, quantified and contextual view. Select other views as deemed applicable.
      - Additionally, the poster should support the project team to defend a trade-off that was made in the concept definition stage with relevant stakeholders
    - **Poster 2 – System Definition**
      - Explain the defined system solution from at least a functional, physical and quantification view. Select other views as deemed applicable
      - Additionally, the poster should support a discussion on a specific trade-off in the system, so that you can discuss this trade-off with relevant stakeholders
    - **Poster 3 – System Realization**
      - Explain the planned realization of your system in your project from at least a functional, physical and quantification view. Select other views as deemed applicable. Focus on the realization system (prototype), which might be different than the envisioned solution in the System Definition stage
      - Additionally, the poster should support a discussion on a trade-off, for example the relevancy and scope, of the envisioned realization
  - Include a title and short introduction that explains the scope and purpose of the poster. It is NOT required to deliver the “text side”, only the “model side” is required, but the scope needs to be clear!
  - The posters should support design discussions with a client and other potential stakeholders. Therefore, there should be a focus, especially with the use of visual aids on a specific trade-off in the system, and not necessarily on explaining everything that you did in that specific development stage (concept definition / system definition / system realization)

- You are not limited to use only one model or diagram per type of view
- Aim to provide a coherent visual design style and utilize storytelling – link different views where possible so there is not a sense of “we copy-pasted 4 diagrams and a few pictures on an A3”
- Stick to the A3 paper format and make sure all text is readable when having the poster on a table in front of you
    - You thus have to be selective in which information you visualize!
- Use references where applicable, you can make a separate box for those

- **Assessment Format**
    - Submit a PDF version of the posters on Canvas on the provided Assessment page. Clearly indicate group members and the theme of the posters in the filename. As filename, use the format “GroupX_Concept Definition.pdf”, etc, where X is your group number or name.

The submitted posters are graded according to the provided rubric after a group project exam. Bring a print out of the posters to the project exam

Appendix II – "SE Posters" Assessment Rubric

The following table gives an overview of the assessment rubric for the SE posters assignment. The learning outcomes listed are sub-indicators of the overall learning outcome related to this assessment. Specifically, 1a concerns the systems definition poster, 1b the system definition poster, 1c the system realization poster and 1d addresses the overall capabilities of the students to discuss the system as a whole during the assessment.

Related Learning Outcome	Indicator	2	4	6	8	10
1a	The student has delivered a visualization of the concept definition which is about defining the problem, avoids the solution and supports a specific discussion topic in the problem domain.		Unclear goal and/or scope choices	Sufficiently clear goal but weak link to scope choices	Clear goal and strong link to scope choices	Clear goal and thought-provoking scope choices
1a	The student has delivered individual diagrams as part of the overall visualization that are internally consistent and include at least a context, functional and requirements view		Inconsistent diagrams, requested views omitted. Not useful for design discussions.	Requested views present but diagrams barely sufficient in quality. Information for design discussion lacking.	Requested views present including useful additions with consistent content. Serves properly for a design discussion.	Views and diagrams are consistent and innovative. Poster perfectly serves and directs design discussions.
1b	The student has delivered a visualization of the system definition which is about the design of a final envisioned system and supports a specific discussion goal in the solution domain.		Unclear goal and/or scope choices	Sufficiently clear goal but weak link to scope choices	Clear goal and strong link to scope choices	Clear goal and thought-provoking scope choices
1b	The student has delivered individual diagrams as part of the overall visualization that are internally consistent and include at least a functional, physical and quantification view		Inconsistent diagrams, requested views omitted. Not useful for design discussions.	Requested views present but diagrams barely sufficient in quality. Information for design discussion lacking.	Requested views present including useful additions with consistent content. Serves properly for a design discussion.	Views and diagrams are consistent and innovative. Poster perfectly serves and directs design discussions.
1c	The student has delivered a visualization of the system realization which is about the design of a fit-for-purpose realization system and supports a specific discussion goal in the realization domain.		Unclear goal and/or scope choices	Sufficiently clear goal but weak link to scope choices	Clear goal and strong link to scope choices	Clear goal and thought-provoking scope choices

1c	The student has delivered individual diagrams as part of the overall visualization that are internally consistent and include at least a functional, physical and quantification view		Inconsistent diagrams, requested views omitted. Not useful for design discussions.	Requested views present but diagrams barely sufficient in quality. Information for design discussion lacking.	Requested views present including useful additions with consistent content. Serves properly for a design discussion.	Views and diagrams are consistent and innovative. Poster perfectly serves and directs design discussions.
1d	The student is able to explain the relations between the problem, solution and realization poster and the relations between the three topics in the project		Not able to explain connection between posters, no understanding beyond posters	Able to explain connection between posters, limited understanding beyond posters	Provides value adding connection between posters, good understanding beyond posters	Innovative connection between posters, expert understanding beyond posters
1d	The overall delivery has a cohesive and consistent visual design that supports stakeholders in their understanding of the presented information		No cohesion between different posters visually and storytelling wise. Hard to gain understanding of system based on posters	Limited cohesion between different posters visually and storytelling wise. Possible to gain understanding of system based on posters	Good cohesion between different posters visually and storytelling wise. Easy to gain understanding of system based on posters	Excellent cohesion between different posters visually and storytelling wise. Posters together allow stakeholders to truly envision the key characteristics of the systems

Appendix III – “SE Posters” Assessment Examiner Questions

The following questions where prepared as (optional) prompts for the examiners to discuss the posters (or A3AOs) with the students in the oral assessment.

1. Could you select a stakeholder and describe how this stakeholder may interpret your poster(s)?

2. What kind of information would you like to collect through a specific discussion based on this poster?

3. In what kind of setting can these posters help to achieve what kind of goal?

4. Will you use these posters in your project with your client and stakeholders? If so, why? If not, why not?

5. How did your project characteristics influence the design of these A3AOs?

6. What does a SWOT for the A3AO as a tool look like? Particularly what threats do you see and what are remedies?

7. Did you apply systems thinking in the making of your A3AOs? If so, which and why? If not, why not?

8. ‘The knife cuts both ways’… Making an A3AO is valuable but using an A3AO for a discussion also is. Could you compare these two uses of this Systems Engineering tool? Could you make a distinction between the three SE-domains?

9. How does the A3AO compare to alternative ways of overseeing and communicating your system-in-the-making?

10. How do the relations between the poster illustrate the systems engineering process for your particular project?