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Responsible Ethical Learning with Robotics

Decisions and values

Engineering design as a pragmatic and sociomaterial negotiation process

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Decisions and values:

Engineering design as a pragmatic and sociomaterial negotiation process

By Jessica Sorenson

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Decisions and values: Engineering design as a pragmatic and sociomaterial negotiation process.

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Foreword

Responsible Ethical Learning with Robotics – REELER – is an interdisciplinary H2020 project funded by the European Commission with 1,998,265 EUR from the 1st of January, 2017 – 31st of December, 2019. Its main objective is to develop the REELER Roadmap for responsible and ethical learning in robotics. The project involves four European partners from the fields of anthropology, learning, robotics, philosophy, and economics, who work closely together in a research-driven collaboration between SSH-RRI and Robotic-ICT communities. Together, they aim to raise awareness of the human potential in robotics development, with special attention to distributed responsibility, ethical and societal issues, collaborative learning, as well as economic and societal impacts. The REELER Roadmap aims at aligning roboticists' visions of a future with robots with empirically-based knowledge of human needs and societal concerns, through a new proximity-based human-machine ethics that takes into account how individuals and communities connect with robot technologies. REELER's comprehensive research methodology includes a design-anthropological approach to onsite studies of roboticists' laboratories and daily work, as well as onsite ethnographic studies and impact studies of present and potential affected stakeholders. The project also includes quantitative research in geographical distribution of patents and an AMB (agent-based model) research approach. Furthermore, the project makes use of novel methodologies to give both robot-designers and affected stakeholders a space for mutual exchange about a robotic future, built around a number of REELER's ethnographic case studies of robots being developed in Europe. These novel methods include experiments with mini-publics, role play, social drama, and also explorations of the established sociodrama approach with professional sociodramatists. REELER aims to include all relevant aspects of this research in the roadmap, which will present ethical guidelines for Human Proximity Levels (HPL) in design work, as well as prescriptions for policy makers and robot-designers for how to include the voices of new types of users and affected stakeholders. The project aims to present an agent-based simulation of the REELER research to be used by roboticists and policymakers. The working papers presented in this series present ongoing research results, literature reviews, and position papers.

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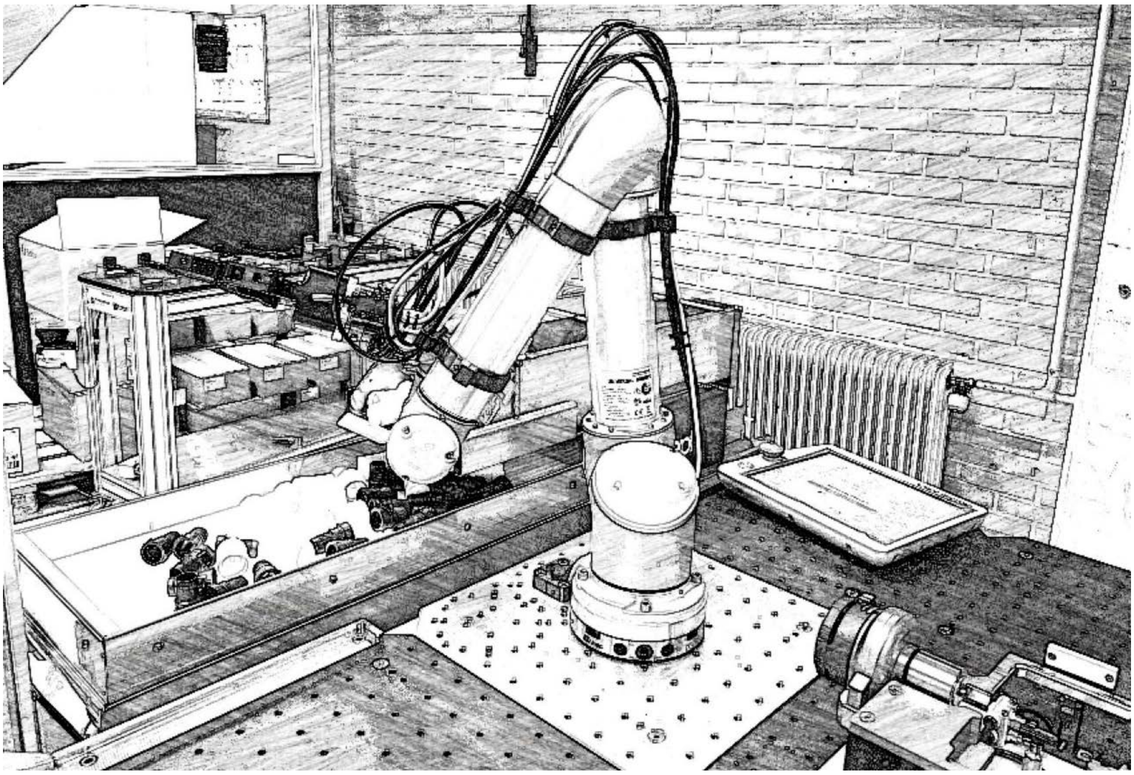
DECISIONS AND VALUES:

ENGINEERING DESIGN AS A PRAGMATIC AND SOCIOMATERIAL NEGOTIATION PROCESS



Jessica Sorenson

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Cover image: Industrial robotic cell at a factory in Denmark

CONTENTS

THESIS STRUCTURE

This thesis is separated into 8 chapters, preceded by a summary and succeeded by an appendix. In chapter 1, I provide a background for this thesis, including my own motivations and the larger context of the fieldwork, to ground the analyses in chapters 4, 5, and 6, and the discussion in chapter 7. In chapter 2, I present the fieldwork underlying this thesis: the construction of the empirical field, the formation of the research problem, the ethnographic methods used, the data produced, and the analytical approach. Chapter 3 introduces the theoretical framework: the methodological and analytical concepts, perspectives, and theories used in the fieldwork and analysis. The analysis spans chapters 4, 5, and 6. Chapter 4 presents design as a pragmatic process, showing how engineers' conceptions and plans are linked to their situated decision-making and problem-solving practices. Chapter 5 presents design as sociomaterial practices: social negotiations and materially-mediated design decisions occur within a particular social arrangement. In chapter 6, the analysis turns to a critical examination of engineering ethics. Formalized ethics are ineffective and ethics are left out of engineering practices. In chapter 7, a discussion is introduced in which I suggest a shift to a pragmatic value-oriented engineering via ethnographic interference. Chapter 8 concludes the analysis. The appendix includes selected fieldwork material.

SUMMARY

The purpose of this study is to shed some light on robotics engineers' decision-making processes, to perhaps find room for ethical reflection within the design process, through an investigation of their *sociomaterial assemblages* and the activities occurring therein. The intention is to critically examine engineering ethics by analyzing actual robot development practices against the backdrop of current engineering ethics strategies and proposed regulations of robot developers. This study contributes to the fields of design and organizational anthropology, and philosophy of technology, by exploring the nature of engineering design, the *social arrangement* of the engineers' decision-making practices, and by calling into question the place of ethics in engineering and the role of the ethnographer in provoking a value-oriented engineering design.

This study involved a five-month ethnographic fieldwork among robotics engineers in a collaborative industrial robotics design project in Denmark. A *sociomaterial perspective* is used methodologically and analytically to capture the entanglement of social and material design practices, while a *social ethics* perspective examines the *social arrangements* that shape ethical decision-making. Methods included participant observation, object elicitation, ethnographic interviews, and document analysis. Data was recorded in the form of field notes and fieldwork summaries, audio recordings, selective transcripts, and digital photographs. Data has been analyzed from STS approaches, including sociomateriality and postphenomenology. Empirical findings support the perspective that engineering design is a pragmatic and sociomaterial process of negotiation.

First, it is shown that *design is pragmatic* in that engineers' orientations toward design emerge from their design practices. Engineers conceptualize design in relation to schematic design theories. A comprehensive analysis of design process models, supported by conversational interviews, unveils a kind of procedural *engineering thinking* that is codified in their design plans and represented in design artefacts, such as specification sheets. The theoretical perspectives embedded in these *inscriptions* are translated into explicit design decisions. However, participant observation and robot mapping (object elicitation) uncover more implicit design practices that contradict the engineers' structured thinking around design, revealing a discrepancy between engineers' *plans and actions*.

Then, it is shown that *design is sociomaterial* in that engineers make design decisions through materially-mediated social negotiations. From an analysis of dialogue taken from observations and semi-structured interviews, it is shown that the engineers enter negotiations from within their own *object-worlds*. As they undertake design decisions regarding the robotic cell which acts as a *boundary object*, they work across these worlds to negotiate understandings, interests, and agency. A postphenomenological analysis of these negotiations shows that design decisions are frequently *mediated* by design artefacts, which show through in design actions when they become *conscription devices* that organize work, or *inscriptions* which lose meaning and fail to represent the material object when not performed. It is argued that conceptions of design are *situated*, based on the observed *multistability* of the robotic cell, the ontology of which is *relational*, dependent on the changing social context – e.g. the engineers' object-worlds. An argument is made that when the engineers traverse these boundaries of understandings and motivations to co-create, they form *new realities*. It is then asked how ethics or values might also be negotiated in these processes of *world-making*.

Finally, the study includes a document review of existing engineering ethics, which are found to be virtue-based, deontological, and oriented toward the individual engineer. Empirical findings on how engineers talk about ethics and engage with values in the design process suggest that ethics is not included in their work. The conclusion to the analyses points to a discrepancy between systematic ethics and design approaches and the very pragmatic and social aspects of engineering design. Thus, a proposal is made, to move from engineering ethics to value-oriented engineering (*or a value-sensitive design*); and *ethnographic interference* might be the means by which this is achieved. The final premise of the study is that ethnographers might play a role in bridging the gap between theoretical ethics and design praxis through the use of a pragmatic and *social ethics* approach which would examine existing social arrangements to find place for *human values* in everyday sociomaterial design practices.

1. INTRODUCTION

This thesis is the product of a five-month fieldwork among robotics engineers involved in a collaborative industrial robotics project (hereafter referred to as HECHO)[1], in cooperation with a technological institute (GTS). I studied how these engineers negotiated decisions within this collaborative industrial robotics project, with a mind to how engineers engage with ethics and values in the design process. In this chapter, I present a backdrop for this study, to give context to the analyses and discussions that follow. The HECHO project emerged within the field of industrial robotics, supported by a national and international innovation discourse and related funding structures. Parallel to the innovation discourse is an effort to regulate robotic technologies and the engineers that make them. These push and pull factors motivated the fieldwork behind this thesis.

1.1 INDUSTRIAL ROBOTICS

In manufacturing, production processes are sometimes organized into workcells. These cells typically contain machinery, people, or both. A robotic cell, is a type of workcell that includes a robot – usually a robotic 'arm' as one component in a larger production setup. The image in figure 1.1 shows a modular robotic cell, the HECHO cell, which is used in a factory in Denmark to assemble and package a product part. The robot's primary function is 'pick and place', which is essentially moving things around.

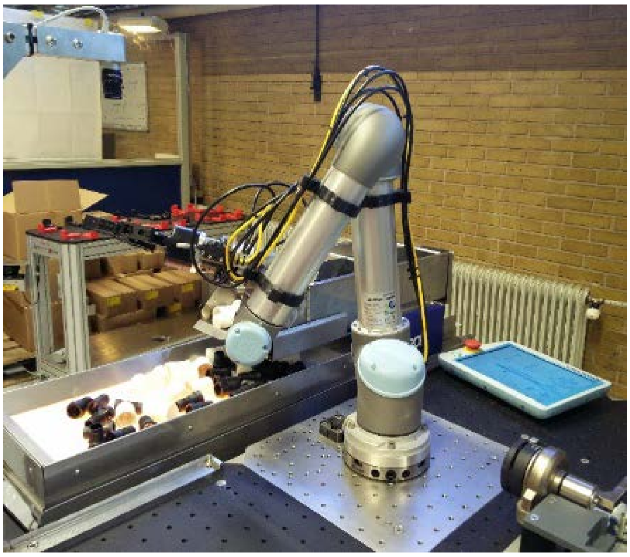


Figure 1.1: The HECHO robotic cell at a factory in Denmark

The arm used in the HECHO assembly workcell is a UR5 collaborative robotic arm, introduced in 2008 by Universal Robot as the "world's first collaborative robot" (co-bot) – a cheaper, safer, industrial arm that can be used uncaged in human-populated production lines.[2] From 1959 when the first industrial robot arm, Unimate, debuted, industrial robots had been separated from manual (human-performed) production processes. Today, there are roughly 1.8 million industrial robots operating worldwide, including some co-bots (International Federation of Robotics 2017). Co-bots are expected to be the next big wave in robotics, based on their use in flexible automation for small- and medium-sized manufacturers (SMEs) (Bogue 2016, 10). The HECHO cell was created specifically to address the needs of SMEs by providing flexibility for multiple, low-batch production processes. The primary site of development for this cell was in southern Denmark, on the island of Fyn, in the city of Odense – a self-branded robotics hub.

1.2 INNOVATION DISCOURSE

Odense has declared itself a "modern Danish city with a hub for robot technology and innovation".[3] This rebranding began in earnest at the millennial turn when the regional and municipal governments began

[1] This thesis includes the use of pseudonyms for reasonable privacy.

[2] https://www.universal-robots.com/no/om-universal-robots/nyhetssenter/de-samarbeidende-robotenes-historie/.

[3] http://english.odense.dk/about-odense.

investing in robot technologies in order to stimulate economic growth in an island community.[4]

> We just started to say we are a Northern European robotics city, and that helps a lot. And suddenly, we *are* it, because we are saying it.
>
> (Manager of government-backed start-up hub)

The local government created Odense Robotics, an organization that brought together the interests of robotics companies and manufacturing companies with the support of the local university and government funding. Their efforts have resulted in a growing cluster of robotics and other technology companies in Odense and surrounding areas.

> [*What do you think were the changes that made it possible to get from where you were ten years ago to now?*]
>
> I think it was the municipality's decision.
>
> [*So it's a conscious effort?*]
>
> Yeah, it's not something that just happened…I think we [Odense Robotics] are formalizing what happened in Silicon Valley. Because we also have network meetings where the companies are coming and discussing. So I think in Silicon Valley it just happened because the right people were there at the time. Here [in Odense], it was an active choice. I don't think it would have been so nice if we didn't have that awareness.
>
> (Manager of government-backed start-up hub)

There have been parallel efforts by the Danish national government and the European Commission to encourage automation and digitalization: In particular, Denmark's Responsible Research & Innovation platform, part of the country's Innovation Fund,[5] and the EU Horizon 2020 research and innovation framework program, of which one focus is SMEs.[6] Denmark's Innovation Fund, in a public-private partnership with companies, universities, and 'advanced technology institutes', finances the Manufacturing Academy of Denmark (MADE). MADE's goal is "applying research, driving innovation and strengthening education to improve the competitiveness of Danish manufacturing…by working in collaboration with companies, universities and [technological] institutes to make Denmark the world's most competitive manufacturing country."[7] All of these governmental bodies and their goals have contributed to the automation of manufacturing and other industries, and are complicit in the construction of an innovation discourse in Europe and in Denmark.

In the Danish manufacturing/production industry, this innovation discoursed is backed by a pro-automation argument, which was repeated by nearly every participant interviewed:

> Hah! Let me just start by saying, as you are probably aware, that we are preserving jobs rather than losing jobs.
>
> (University professor)
>
> An automated workplace is a competitive workplace. And a competitive workplace is a

[4] http://nyheder.tv2.dk/samfund/2017-05-03-vildt-roboteventyr-udvikler-sig-i-odense-nu-er-der-over-100-virksomheder.

[5] https://innovationsfonden.dk/da/rri-i-innovationsfonden.

[6] https://ec.europa.eu/programmes/horizon2020/en/h2020-section/innovation-smes.

[7] http://en.made.dk/.

> well-staffed workplace.
>
> (Technological institute website)

This rhetoric comes from a study out of Syddansk Universitet (University of Southern Denmark) in Odense, which showed that when production processes are automated the company is less likely to move overseas and is able to retain Danish workers (Arlbjørn et al. 2013). These two arguments, for retaining Danish jobs and Danish production, were repeated frequently when the topic of ethics was raised. The innovation discourse and the particular rhetoric about saving Danish industry exemplifies the particular way that ethics is understood within this robotics community (see chapter 6).

1.3 Funding structures

In Denmark, the political push for robotics and automation is also supported by funding schemes that award 'innovation'. These grants, delivered within the context of the innovation discourse, push the discourse and the technologies that emerge from it. Danish industrial robot developers can take advantage of two types of government funding schemes: 1) block grants, called *resultatkontrakter* ('result-contracts'), for broad research goals, and 2) categorical grants for specific national projects, resulting from calls.

For result-contracts, funds are awarded for the development of a particular area of industry, quite broadly, but are not tied to any specific project. This reflects the government's open support for "the development of new technological competencies and services to benefit Danish industry."[8] In the national projects, the Danish government sets particular goals for how they'd like to develop Danish industry (manufacturing, for example), then the institutions define a specific project that will meet these goals. These early project specifications tend to define big-picture design decisions, and may therefore be a particularly relevant site for ethical considerations. Unlike the result-contracts, this money is specified for particular tasks in a particular research project:

> Those that are funded through the calls are more restricted, it's a more confined space where you can define a project. But still, they say 'We want to improve this. Propose a way to do that.'
>
> (Robotics engineer)

> Yeah, so usually the proposal sets the frame- you have to put it in and you have to paint the picture afterwards.
>
> (Software engineer)

Both funding schemes play some part in the development of robots, but the proposal made to secure the result-contract has a more direct effect on later design decisions (see chapter 4) and on ethical decision-making agency (see chapter 6). The aforementioned technology-driven innovation discourse, and the funding activities that bolster it, are at the root of the collaborative industrial robotics project on which this thesis is centered.

1.4 The HECHO project

For five months in 2017, I studied the HECHO robotic cell and the people and practices involved in its development. The HECHO project was funded by categorical/result-contract grants, which emerged from

[8]Translated from Danish: "Resultatkontrakterne giver mulighed for udvikling af nye teknologiske kompetencer og serviceydelser til gavn for dansk erhvervsliv." https://gts-net.dk/gts-institutter/fokusomraader/resultatkontrakter/

a larger research and development structure in Denmark. The project was part of a large public-private work package, with the goal to "develop flexible user friendly robot solutions that enable rapid automation at low cost in small series production." This codified goal would later define particular values during the development of the HECHO cell (see section 4.3).

The HECHO industrial robotic cell (figure 1.1) was built upon technologies from a previous project, DIEGO (see Appendix), and was the basis for its successor, the STACK/Adapt Cell. All three of these cells consist of a utility cabinet containing industrial pc controllers and other electronic components, a tabletop with a grid of holes for mounting, a collaborative robotic arm with a gripper, and various "modules" which are separate automated machines. The HECHO cell was used to automate two assembly processes: assembling a product part, and packaging the entire product in a clamshell container. The robot was used to move parts into position so that the modules could, press, package, or transport the pieces.

The HECHO project was carried out by a consortium of five partners, spread across Denmark: GTS, a technological institute; two universities; ManuTech, a machine manufacturer and system integrator; and Ingram, a manufacturer. Together, these partners attempted to create a modular robotic workcell capable of easy reconfiguration for low-batch manufacturing processes at a production factory in Denmark. While each of the collaborators had their own motivations and interests in the project (which were negotiated during the design process), the entire project emerged from an innovation discourse-driven structure of funding and expectations.

My own introduction to the HECHO cell came during a meeting the head of robotic technologies at GTS. He showed me a promotional video 'The Robot That Can Retain Danish Jobs'. Already, the project had a political voice to it that called out to me – a robot that saves jobs – a "flexible" solution that can be easily configured in small- and medium-size companies that can't afford traditional, permanent automation. This narrative fit with the innovation aims of the EU Commission and with Denmark's innovation and research policy, and added to my research motivations.

1.5 Fieldwork motivation

Just as the government is leading a push for the development of robotic technologies, through funding strategies and innovation policies, it is also tasked with addressing societal impacts the innovative technologies bring. One participant explains that the government is somehow responsible for the creation of robots, and any effects they might have on society:

> I don't know, you can say that the government is setting the direction, saying that we should install more robots. And they know about the societal ethics, effects that it will have. So they are somehow responsible.
>
> (System integrator)

In the European Union, the government is currently setting the tone for regulation. In the months preceding the start of this thesis fieldwork, the European Parliament called on the EU Commission to regulate robots, and to hold makers responsible for the effects of their creations (European Parliament 2017). The resolution grouped together designers, engineers, system integrators, programmers, and researchers as "producers" or "manufacturers" of robots and ascribed to them all broad ethical responsibility, in the form of legal liability, insurance, licenses, codes of conducts, and charters. There was much ambiguity and little recognition for the diversity in the types of robots being produced, and in the design processes through which they are developed. The proposed top-down, prescriptive solutions relied on normative ideas of agency and rationality in design decision-making processes. This sparked an urge to understand who some of these “producers” were and how they went about designing their robots. Intrigued by the push for technology-driven innovation from funding and research schemes in Denmark and the EU at large, along with the parallel parliamentary action promoting the regulation of robots and concomitant liability of robot producers, I made the decision to do ethnographic fieldwork surrounding a robot under development.

2. METHODOLOGY

In this chapter, I present the fieldwork underlying this thesis. I begin with the construction of the empirical field (the people, places, things, and practices I studied) around the robotic cell, and the research problem inspired by the field. I then present the methods used to explore the research problem, and the data that was created through the use of these particular methods. Finally, I present my analytical approach to the field – how I framed the field, enquiries, and my own understandings.

2.1 EMPIRICAL FIELD

I set out to conduct ethnographic fieldwork amongst Danish robotics engineers to understand something about their particular design processes – precisely *what,* I had not determined but would discover through my initial fieldwork. In ethnographic research, an empirical field is composed of people (or other actors), places, things, and practices. The researcher must "laboriously construct" the field – that is, delineate the boundaries of study (Amit 1999, 6). The field is not a thing in itself, but is rather the meshwork (Ingold 2011) created by the ethnographer as she traces out the relations, interactions, and connections between the people (including herself), places, and things (conceptual and material).

In line with other scholars studying technologies (Haraway 1990; Walker 2010; Latour 1993; Ingold 2010), I opted for a "follow the thing" approach (Marcus 1995), which would involve finding a robot under development and studying the *sociomaterial assemblage* (or, meshwork) in which it was situated (Leonardi 2013; Suchman 2007; Ingold 2011). This approach breaks from the anthropological tradition of beginning with a foreshadowed research problem (described by Malinowski in 1922) and then finding a physical field site particularly suitable for exploring that problem (Hammersley and Atkinson 2007, 26-29). I found two particularly problematic assumptions with this approach: that an empirical field is an existing physical space waiting to be found (it's not), and that empirical fields (the spaces, the people, the things of study) are inert (they're not).

> The notion of immersion [in a field] implies that the 'field' which ethnographers enter exists as an independently bounded set of relationships and activities which is autonomous of the fieldwork through which it is discovered. (Amit 1999)

I did not wish to foist my research problem upon the people and practices that the problem should describe; rather, in following the thing, I would define (and redefine) my research problem through the fieldwork itself.

I began by identifying areas of interest (robotics, design, ethics) and conducting document analysis and web research to "case" potential sites (robotics companies and research institutes in Denmark), as suggested by Hammersley and Atkinson (2007, 29). I made contact with the head of robot development at GTS, a technological institute, to learn more about their different activities and to identify our shared interests. Together, we decided that the HECHO robotic cell would be a suitable point of departure for my ethnographic inquiry, primarily because this project was a rather public research project and access would not be a problem.

I built my research around the *thing* at the center of the HECHO engineers' practices – in this case, an industrial robotic cell being developed – and traced the human activity tied to the thing in order to construct the field of inquiry. Following the thing led me into conference rooms, electrical engineering workshops, demonstration halls, factory floors, and lunch rooms. In these places, I found mechanical and electrical engineers, programmers, software developers, system integrators, factory managers, and production engineers.[9] The fieldwork itself was multi-sited (Marcus 1995) by nature, as the project participants and the machine's development were dispersed across Denmark. This fieldwork was also multi-sited in that the field was not a physical place in itself, but rather a social space of investigation defined by myself as the ethnographer, by the participants and their activities, and by the arrangement of people and things - in a type of *world-making* that is constructing the field (Amit 1999, 6; Rapport & Overing 2002, 391; Goodman 1984, 21). My own involvement in the sociomaterial spaces I was investigating would also shape the field throughout the fieldwork (see section 7.2 for more on the ethnographer's role).

Experiences in the field would also inform my formulation of a research problem, and the continuous adaptation of research questions and methods throughout the process. From the initial fieldwork (which involved conversational interviews, document analysis, and literature reviews), and motivated by current events (i.e., the European Parliament's 2017 resolution), I loosely formulated a research problem aimed at exploring decisions made in processes of robot development, with special attention to the value-laden decisions or ethical aspects of design.

2.2 Research problem

By beginning with the robot as an empirical object, and drawing the empirical field around it, I came to define the following research problem:

> *How are design decisions – and by extension, values – negotiated in a collaborative industrial robotics project?*

The underlying research motivation was to find out how robot developers engage with ethics in their everyday work. I operationalized my research problem into research questions, including the following:

- How do engineers make design decisions in their everyday practices?
- What is a decision? How do I know when one is made?
- What kind of values do engineers consider in these decisions?
- What ideas do engineers hold about ethics and design? Where do these come from?
- Do engineers consider the ethical implications of their design?
- How do engineers talk about ethics and values?
- What are the structural, social, cultural, and material constraints on decision-making agency?
- How do formalized approaches to ethics and design affect engineering practices?

In order to explore these questions and others, I conducted ethnographic fieldwork among the developers of the HECHO industrial robotic cell.

2.3 Methods & data

Ethnography has been described as a continuous process of discovery, "like grabbing a ball of string, finding a thread, and then pulling it out," (DeVault & McCoy 2006, 20). This process was iterative in my research, in that each method was chosen to answer certain research questions. These methods then produced

[9] *A note on terminology*: While the participants in this study held different titles and specialized in different areas of practice, and are certainly not a homogeneous group of people, I nevertheless refer to the members of the HECHO project, collectively, as 'engineers'. This is because they all studied and practiced various forms of engineering, and because I feel that the term 'informants' connotes a hierarchy, whereas the term 'participants' denies one.

particular data, which informed new questions, and thus influenced the further selection of methods. I used participant observation, for example, to learn about the HECHO engineers' everyday decisions, interactions, and other activities. These observations, however, brought to my attention particular unsolicited questions of culture (such as jargon, dress codes, and education) which affected communication and collaboration among the robot developers. By involving the participants in a method of object elicitation, mapping the robotic cell, I learned about the different ways they thought about and related to the robot – viewing it simultaneously as a product, a research object, and a source of labor. These differences seemed to have an impact on their decisions in the cell's development (see chapter 5). Through media analysis and qualitative interviews (Kvale 1996), I learned more about the participants' views on ethics and decision-making, which directed my attention to a main finding: the discrepancy between how the engineers approached decision-making and ethics in a systematic way, and how their decisions actually unfolded pragmatically and sociomaterially during the design process, leaving ethics relatively unexplored and human values neglected.

Conversational interviews. I began with casual, open conversations in the initial fieldwork. It was from these early conversations that I was able to identify the HECHO project as a research object, gain access to field sites, and develop a research question. After having developed a level of mutual ease, and seeking more particular information, I transitioned to instrumental conversations (Madden 2010, 65-67; Davies 2008, 105). These interviews produced baseline information about the project and particular project management approaches to decision-making.

Literature reviews & document analysis. Early document analysis was critical in forming an initial research question. I reviewed academic literature, design process models, company and engineering association websites, specification sheets and other technical documents, meeting minutes. These texts were used instrumentally to fill in informational gaps, but also analytically in understanding formalized approaches to engineering ethics and design planning.

Timeline interviews & robot mapping. I used timeline interviews (Adriansen 2012) to construct a "life" history of the HECHO project. Concurrently, I experimented with robot mapping, a type of object elicitation using specification sheets and other engineering artefacts to construct the field around the robotic cell represented by these design artefacts.

Semi-structured interviews. After some time in the field, I developed more targeted analytical interests, which the early data being produced from conversational interviews could not answer. I shifted to semi-structured interviews, asking ethnographic questions to elicit narrative or descriptive responses (Spradley 1979, 83-88) using real-life narratives as examples to draw out the engineers' ethical reflections.

Participant observation. I observed in labs, meeting rooms, exhibition and innovation halls, workshops, cafes. This method opened the research to new inquiries about culture, disciplinary boundaries, material mediation, and hierarchy in collaboration. I took detailed field notes and took audio recordings where conversation analysis might be particularly useful (project meetings, e.g.)

Data. The data recorded includes roughly 25 audio recordings & selective interview transcripts, multiple digital photographs, project documents, handwritten field notes, and typewritten fieldwork summaries.

These ethnographic methods and the resulting data used to explore the empirical field, made it possible for me to learn more about who made the robotic cell, how they negotiated decisions in their design processes, the social arrangements around these processes, and whether there was room in the design process for ethical reflection.

2.4 Analytical approach

The fieldwork upon which this thesis is built was multi-sited, centered around the industrial robotic cell as a point of departure in studying the engineers who built it, in a follow-the-thing approach (Marcus 1995). I have paid particular attention to materiality. Actor-Network Theory (ANT), therefore, might seem appropriate as it has brought things to the forefront, and is frequently used in Science and Technology Studies. However, I decided not to use ANT through the course of the fieldwork, or in analysis. ANT tends to describe people and things in flat networks, giving more agency to the material, but focusing a bit too much on relations (Jackson and Piette 2015, 22) and on "large networks that span beyond the situation at hand…[losing] sight of particular practices that can be observed when human actors deal with objects," (Roehl 2012, 52). The people and things I observed were not neatly connected in relational networks, but were rather hopelessly entangled and shifting all the time. I was interested less in large chains of events and branching networks, and more in the complexity of particular decision-making moments in a project. Therefore, I opted to follow an approach that draws primarily on the work of Tim Ingold (2011) and Lucy Suchman (1987; 2007) to describe these people and things, and the behaviors that hold them together. In constructing and describing the field, I've relied on Ingold's framing of a living system as a *sociomaterial assemblage* of people and things, which compose the world (Ingold 2010, drawing on Heidegger).

In my fieldwork, I followed the thing, tracing out various lines in the participants' particular meshworks (Ingold 2011) where they entangled with the industrial robotic cell. I explored these entanglements and pragmatic human activities, which comprise perception and action (Ingold 2011, 64-65), as *situated practices*, building on the work of STS scholar Lucy Suchman (1987; 2007) to understand activities as social, contextual interactions. Finally, I've turned to Louis Bucciarelli's (1988) and Lucy Suchman's (2001) studies of engineers to analyze these situated practices and to develop an understanding of engineering design as a social process.

As this fieldwork developed, so too did I. As I came closer to the robotic cell, and the practices and people shaping it, my understandings changed, and so the theoretical concepts and analytical perspectives that guided my research choices also changed. When I began to identify preliminary findings, such as the key role of sociomaterial assemblages in decision-making, I shifted my perspective and my ethnographic gaze to design as a social process. Consequently, in my analysis, instead of looking at the participants as individual moral agents making decisions, I began to see them through the lens of *social ethics* – people negotiating ethical decisions within a particular sociomaterial arrangement (Devon & Van de Poel 2004). When in the course of the fieldwork, I came to understand the pragmatic nature of the engineers' work, I began looking more at values reflected in their everyday design practices, broadening my prior focus on their expressed perspectives on design and ethics. This gaze shift entailed a shift in methods, from interviews to more participant observation. Thus, the fieldwork was a learning process with a continuous revolution of inquiry, methods, data, and analysis.

3. Theoretical Framework

This theoretical framework supported my orientation in the field, informed my selection of methods and inquiries, and facilitated analysis of the empirical findings through analytical perspectives and theoretical concepts that explained the practices observed. In order to investigate how design decisions and values were negotiated in this collaborative industrial robotics project, I began by examining existing approaches. In this chapter, I present decision theory and cognitive approaches to studying decision-making; these approaches have a focus on the rational individual and neglect the social and material aspects of decision-making. Following my own interests and motivations in the project, I have instead taken a sociomaterial approach to studying decision-making as materially-mediated social processes of negotiation. This methodological perspective would help me to elucidate the engineers' design negotiations with a regard for the very material and social aspects of engineering practices. As part of my background work, I also reviewed anthropological studies of values and value-oriented design theories in order to frame my own study and analysis of values. I have chosen a social ethics approach to understanding the social arrangements around ethical decision-making – a methodological and analytical approach which bridges values and decisions under a sociomaterial perspective. Finally, I have analyzed the engineers' practices through a pragmatist perspective, influenced by the engineers' own very pragmatic problem-solving and social negotiation activities.

3.1 Studies of decisions

Decision-making has been extensively studied using approaches from psychology, sociology, economics, philosophy, mathematics, business, and organizational studies (Howard and Ortiz 1971; Boholm, Henning, & Krzyworzeka 2013). These approaches are collectively *decision theory* (Steele and Stefánsson 2016). Decision theory can be prescriptive, predictive, or descriptive (see Bell, Raiffa, & Tversky 1988). With prescriptive and predictive decision-making approaches, scholars typically identify persons as agents (rational or not) with choices (known or unknown); predictive theories then attempt to identify the course of action a person *will* take, while prescriptive theories suggest which course of action a person *ought* to take, given a set of norms (Bordley 2001; Steele and Stefánsson 2016). These approaches tend to address rational decision-making, cognitive processes, and normative (right/wrong) decisions based on risk, utility, and logic. These decision-making behaviors are then measured by probability and mathematical modeling. What these approaches lack, however, is context. They tend to look at the self-contained individual decision-maker. One branch of decision theory, *game theory*, turns toward multiple 'agents', but remains predictive rather than descriptive, relying on rules, strategy, and utility to predict the negotiations between the interactors.

In the ethnographic tradition, I sought not to predict or prescribe decision-making behaviors, but to describe them. I was not concerned so much with the underlying biological or psychological drives that motivate behavior, which is so often the concern of the cognitive, neurological, and behavioral approaches. Instead, I have taken interest in the ways in which people behave, with regards to design decisions, and how they conceptualize their own behavior.

Descriptive decision-making approaches have addressed actual decision-making processes. One such approach is behavioral decision theory, which challenges assumptions about risk, utility, and logic and seeks to complexify the presumed rational decision-maker (Edwards 1954; Fryback 2005). However, behavioral decision theory is still interested in the individual, neglecting the social. Another common angle is the behavioral psychology approach to decision-making, such as Daniel Kahneman's famed work in behavioral economics. Kahneman *did* take into account social structures, norms, etc., but still attempted to explain a mental process of decision-making or the thought processes behind expressed behaviors. Even the anthropologists who have incorporated the social through cognitive or cultural approaches – explaining decision-making behavior through schemas or motives, for example (D'Andrade and Strauss 1992; Hedegaard 2009) – have emphasized the psychological underpinnings of behavior.

In this thesis, rather than emphasizing individual decision-making behavior, or the cognition behind it, the focus is more on decision-making as a social interaction between people (and things) – a negotiation of interests, motivations, materials, knowledge – shaped by the sociomaterial arrangements in which decisions are made.

3.2 A SOCIOMATERIAL PERSPECTIVE

In anthropology, decision-making has been addressed with regard to decision models in medical care (Garro 1998; Kayser-Jones Jeanie 2009), or in political or economic systems (Paley 2004; Maeckelbergh 2013), or with a focus on structural power relations (Folmar 1992; Barlett 1977). Decision-making as a topic itself has hardly been touched in the field of anthropology. However, Åsa Boholm, Annette Henning, and Amanda Krzyworzeka (2013) have done just that; Boholm (2005) has even specifically addressed design. Boholm approaches design decision-making with a mind to social structures, analyzing discursive constraints on a bridge-building project. While Boholm adequately addresses the social aspects of the design project, he does not adequately capture the material – an aspect also neglected completely by decision theory. Engineering design is an implicitly material activity – not just in the creation of artefacts and manipulation of materials, but also in the use of everyday design artefacts, which serve as *boundary objects* and *conscription devices* (Henderson 1991; Latour & Woolgar 1986), such as sketches, videos, specification sheets, etc. To address this missing materiality in decision-making approaches, I have taken a *sociomaterial perspective* in my empirical study and in the analysis.

The sociomaterial perspective comes from a constitutive relationship between the material and the social, as Wanda Orlikowski and Susan Scott explain: "people and things only exist in relation to each other," (2008, 455; see also Leonardi 2013). This type of *relational ontology* can be exemplified by the Heideggerian hammer (Heidegger 2008/1927). A hammer is a hammer because of its relation to hammering: when a person comes to the hammer with the knowledge, experience, or intent to use the material (the wood and metal) to strike something else. It is the social context that defines the material hammer. Conversely, the activity of hammering is an interaction with the material. Without the material hammer to wield, there would be no activity, no *–ing*, at all.

I have therefore constructed and analyzed this field from a sociomaterial perspective to understand the design process by studying the particular assemblage of people, objects, materials, and space in the HECHO project, and the interactions between them. This particular situated approach is frequently used in the fields of Science, Technology, and Society (STS) and organizational studies to study human-technology relations (see for example, Orlikowski 2007; Suchman 1987), and has indeed been used by a few scholars to study robotic technologies (see for example, Suchman 2007; Hasse 2013). The sociomaterial perspective I have used in this thesis might best be described by Niels Christian Mossfeldt Nickelsen in his 2015 paper about welfare technologies:

> From a sociomaterial perspective…agency is the capacity to act that is discovered and untangled by studying how sociomaterial assemblies and local truths emerge. (Nickelsen 2015, 7)

That is, plans and actions are shaped within a particular sociomaterial context. I have departed from the decision theory approach with rational agency, and have instead tried to understand how actual design decisions were made within the sociomaterial assemblage of the HECHO project. I have looked at the interactions and practices that have framed the design of this particular industrial robotic cell as embedded in particular social arrangements: I have observed how the design process was *mediated* by design artefacts (Hasse 2013; Roehl 2012), how collaboration occurred across *object-worlds* (Bucciarelli 1988), and how material design practices reinforced conceptions of the design process (Johri, Roth, and Olds 2013). In these analyses, I have drawn on sociomaterial perspectives, concepts, and theories from science and technology studies (STS) (e.g., postphenomenology, philosophy og technology). The analysis is centered on how negotiations are central to social processes of decision-making. As such, when turning toward engineering ethics, I have aimed for an approach that is socially – not individually – oriented.

3.3 Studies of values

Anthropologist David Graeber has looked across different disciplines for his seminal work on values. Drawing on the work of Clyde Kluckhohn (1951), he describes values as "ideas about what [people] ought to want," (Graeber 2001, 3). Graeber came up with three ways of talking about values: sociologically, economically, and linguistically. Sociological values are "conceptions of what is ultimately good, proper, or desirable in human life," while economic value is "the degree to which objects are desired," (Graeber 2001, 1). From a marketing perspective, Peter Doyle (2009) categorizes values as functional, monetary, social, and psychological. In this thesis, I draw on the definitions from both Graeber and Doyle to adequately capture the values represented in my data. I distinguish between two types of values: human values and functional values. *Human values* refers to the sociological values described by Græber, but also encompasses the social and psychological values described by Doyle – things like identity, human welfare, connection, etc. *Functional values* are related to the solution, including aspects of the robotic cell's functions – things like flexibility, efficiency, etc. I have omitted economic values, because when particular human or functional values are incorporated into the product design, economic value can be generated (Doyle 2009).

In design, human values have been considered alongside functional values as part of the *value-sensitive design (VSD)* framework developed by Batya Friedman and Peter Kahn. Together with Alan Borning, they write that values "depend substantively on the interests and desires of human beings within a cultural milieu," (Friedman, Kahn, & Borning 2006, 349). In this sense, values are a type of cultural or social norm. While most values have been considered culturally relative, anthropologists and philosophers (and of course many governments) have tried to come up with universal values, or human values that are universally held (see Gert 2009); however, such an effort denies the contextual dependence of the values. My use of the term human values, therefore, does not imply any universally valued qualities, but rather suggests generally the *sort* of qualities that a particular user or group might value. For the sake of this argument, I will refer to human values that have been put forth by the European Union (2000) in the Charter of Fundamental Rights of the European Union; these values include dignity, equality, privacy, security, etc. While these are not necessarily values specific to the HECHO users/operators, these are the values behind the European Parliament's proposed regulation of robotics. It is with these human values, and the functional values drawn from the empirical data I've gathered, that I proceed.

3.4 Pragmatism & social ethics

Finally, because engineering is, first and foremost, a practical activity of problem-solving and negotiation, I turn to *pragmatism* to analyze the engineers' practices, and to approach the subject of engineering ethics (Peter Dalsgaard 2014, based on John Dewey's fundamental work; Schmidt 2014). Jon Alan Schmidt (2014) makes the distinction between *theoria* (thinking) and *praxis* (interaction/action) to explain design as a pragmatic process between design plans and design practices. To account for human needs in these plans and practices, I suggest a turn from deontological and virtue ethics to pragmatic human values. I focus my discussion (in chapter 7) on how engineering ethics might be operationalized through value-oriented design practices.

However, because engineering is also a social process of negotiation, I argue for a framing of design practices through the social ethics paradigm described by Richard Devon and Ibo Van de Poel (2004). Social ethics opens up for the examination of a social arrangement surrounding ethical decision-making in design. Devon and Van de Poel (2004) argue that design is "quintessentially an ethical process" and "an iterative social process for making technical and social decisions," (461). The pragmatic negotiations of engineering design are inherently social, and thus inherently ethical – balancing the understandings and motivations – but also values – of one person or group against another. The social activity of engineering design calls for a social engineering ethics. In support of such an ethics, William Lynch and Ronald Kline argue:

> Ethicists need to pay attention to the complexities of engineering practice that shape decisions on a daily basis….Moral choices are made continuously within a stream of ongoing practice, while a variety of different agents with varied interests and experiences shape decision making. (2000, 196-199)

By studying the HECHO engineers' everyday design practices as well as the social arrangements surrounding decision-making, I have highlighted some of these complexities. For example, I have observed structural constraints on decision-making processes in my assessment of the HECHO social arrangements. The engineers were not always negotiating interests or understandings free of hierarchy – their moral agency was contextually dependent (see section 5.1).

Marc Steen (2015), drawing on Langdon Winner (1993), takes it further to say that social constructivists have opened studies of technologies (including their design and development) through examinations and descriptions of sociomaterial assemblages while avoiding passing judgment or bringing up moral and ethical questions. In chapter 7, I venture to say that ethnographers play an active role in shaping ethical realities. By asking particular questions and engaging in a dialogue with engineers about human values, I have already made a political choice.

◊ ◊ ◊

This thesis contributes to the fields of design anthropology and organizational anthropology. Existing bodies of research have laid out perspectives of *engineering design* as social and/or pragmatic (Bucciarelli 1994, 1988, 2003; Schmidt 2014; Schmidt & Dainty 2015; Suchman 2001), of *engineering ethics* as social and/or pragmatic (Devon & Van de Poel 2004; Suchman 2002; Dalsgaard 2014), and of design practices as sociomaterial (Suchman 1987; Suchman 2007). What I hope to have done in this thesis is to present empirical findings that support and bring together these perspectives, and to suggest that pragmatic and sociomaterial engineering design calls for a pragmatic and social engineering ethics.

ANALYSIS

By studying the behaviors and practices of engineers, as well as their social arrangements, I have identified a few empirical findings that support perspectives of design as pragmatic and sociomaterial. In the following three chapters, I present the collaborative design of an industrial robotic cell as a pragmatic design process involving structured planning, and the more implicit practices of decision-making through technical problem-solving, the use of material artefacts, and the social navigation of cultural and disciplinary boundaries. Finally, in examining these social and pragmatic aspects of engineering design, I have considered where there might be more room for the negotiation of (human) values.

In chapter 4, I will show that *the design process is pragmatic* in that the HECHO engineers' orientations toward design emerge from and inform their design practices. These findings are built upon an analysis of design process models & design plans, on conversational interviews, and on recorded observations. In chapter 5, I'll show that *design practices are sociomaterial* in that engineers make design decisions through materially-mediated social negotiations. This analytical chapter was primarily informed by dialogue recorded during participant observation in labs, workshops, and meeting rooms, and during semi-structured interviews. In chapter 6, I will present empirical findings on how engineers talk about ethics and engage with values in the design process, based on ethnographic interviews and observations. These are presented alongside a review of existing engineering ethics approaches, a result of document analysis. The conclusion to these analyses points to a discrepancy between systematic ethics and design approaches and the more pragmatic and social aspects of engineering design. Thus, I suggest a need for a more pragmatic ethics based in engineers' sociomaterial practices.

4. PRAGMATIC DESIGN PROCESS

Engineering design involves both plans and actions (Suchman 1987) within a particular sociomaterial assemblage. In this chapter, I present design as a pragmatic design process wherein the HECHO engineers' orientations and behaviors both shaped their design decision-making processes. They enacted design plans through technical problem-solving activities, and by negotiating ideas, plans, and materials. The engineers' conceptual framing of the design process –their plans- reinforced 'engineering thinking', a structured orientation to design which ultimately constrained their decision-making processes by delineating explicit moments of decision. Nevertheless, there were still many everyday decisions that were made more implicitly through social negotiations. Overall, the engineers' decision-making involves a pragmatic back and forth between consideration and action (or, theory and practice).

4.1 ENGINEERING AS PROBLEM-SOLVING

The primary activity of engineers is to solve technical problems, to create. How the engineers in the HECHO project devised their solutions (i.e., how they made plans in binary, schematic ways), reinforced their 'engineering thinking' orientation toward design. The description of engineers as problem-solvers comes from the etymology of the word, the HECHO engineers' own validation of the definition, and their framing of their work activities in problem-solving language. The word engineer derives from Latin *ingenium*, which means 'contrive' or 'devise'.[10] Consistent with this description, the engineers involved in

[10] Oxford English Dictionary: 'engineer'. https://en.oxforddictionaries.com/definition/engineer

the HECHO project frequently spoke of their work as devising solutions to problems [emphasis added]:

> Maybe often, robotic solutions are going into **solving a problem** for humans.
>
> (Robot consultant)

> But in the end, when we apply for those monies, we are competing with the other research and technology institutes…**How would we solve it?** How would we develop the Danish industry?
>
> (Software engineer)

> Yeah, so we knew it had to be a DIEGO table, so that kind of sets the frame, and then we just need to make the modules to go on top so that **we can solve these** two use cases.
>
> (Software engineer)

Similarly, in the fields of robotics and software engineering, a product is often referred to as a 'solution' or a 'system'. When engineers frame their work in such a way, they position themselves as problem-solvers, providing solutions to customers' problems. This was true for the HECHO engineers as well [emphasis added]:

> When we are involved [in a project], it's not like we are asked to do this like this. We say, "How can we solve this?" and then we propose **how to solve it**. So, we are not given a recipe to follow, we always create the recipe. And if we are given a recipe, we always suggest, maybe, changes to it because it might be smarter to do it in a different way. So we constantly **propose different solutions** to the job, or to the task.
>
> (Robotics/software engineer)

> I think, for most of those, actually physically building the solutions, their motivation is the technical aspects. We just want to make cool robots, no matter what happens with them. And cool solutions. Whereas, I think that most companies would also be run by people who just **want to make cool solutions for people**….Yeah, so there's a difference in those making a robot, building it, and those actually using it….I'm sure that those actually developing the robot would be technical people, just wanting to create a cool robot.
>
> (Robotics engineer)

The last quote really epitomizes the observed and reported activity of the engineers within the HECHO project. These engineers repeatedly emphasized their interest in solving a technical problem, whether it was developing optimized trajectories for the gripper, or getting clamshell packages to seal successfully. These were the close everyday design decision opportunities that were most often undertaken. When the group of collaborators met together in Odense, their discussion centered on problem-solving. They began their project meeting by recounting which "problems" they'd been working on, which they had "solved," and which they should address next. Based on the participants' self-identification, their discourse, the word's origin, and their observed problem-solving behaviors, these engineers might fairly be described as problem-solvers.

The engineers' hyperfocus on solving technical problems has perhaps led to a blindness toward other decision-making opportunities – regarding human values, for example (see section 6.2). The desire to "make cool robots, no matter what happens with them," entails a detachment of the design from its context. This is emblematic of the engineers' typical attitude toward ethics as irrelevant to their task. The engineers did not consider values or ethics to be motivating factors in their daily work.

> When you are trying to solve this problem, you're not thinking about the ethics – you're just trying to figure [out] a solution to something technical. How do I get the robot to move this part from here, to here?
>
> (Robotics engineer)

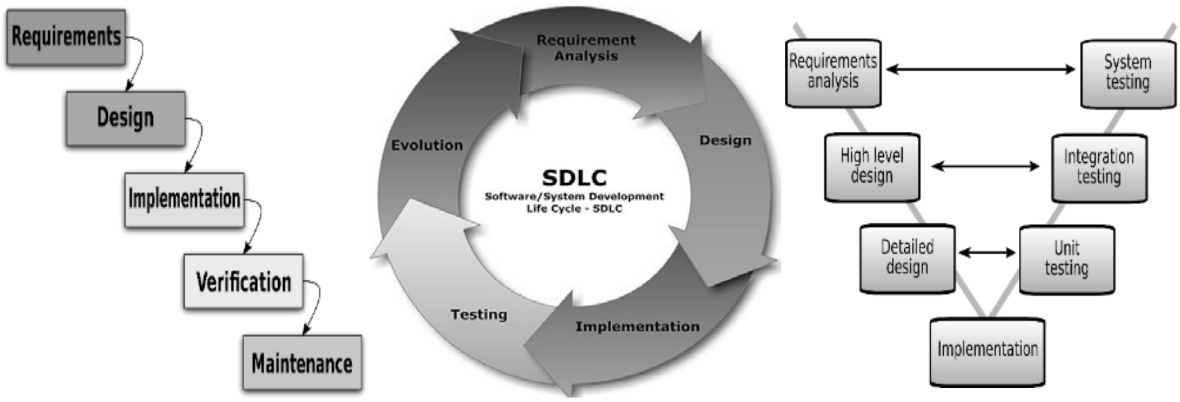
However, when asked about their overall motivation for building the robot, or their consideration of ethics or values in the design process, they sometimes mentioned human-oriented aims, such as saving Danish manufacturing. This points to a discrepancy between the way the engineers approach ethics, as a theoretical moral orientation, and the way they approach design, as a practical problem-solving activity (see chapters 6 and 7 for a discussion of ethics and values).

4.2 Planning & conceptualizing design

Design itself has been described as a pragmatic problem-solving process, using perception to identify problems and conception to envision solutions (John Dewey 1938, in Steen 2015) and action to realize these solutions. One of the pragmatic activities of design is the planning of the engineers' design activities. The ways in which engineers plan, conceptualize, and codify (practice) the design process can not only reinforce their orientation toward design (theory), but this negotiation of the design plan also has real effects on the design decisions occurring throughout the design process.

The HECHO engineers displayed a particularly structured orientation toward their problem-solving work. The engineers conceptualized their design process in very schematic, linear or cyclical ways, relying on design theories, and design plans to explain their ongoing work activities – however incongruous they might be. This engineering thinking around design is bolstered by the conventional ways in which design processes have been depicted, taught, and shared in professional literature and by the HECHO engineers themselves.

As far back as the 1970s, design processes – particularly in software development – have been represented by design models such as the waterfall model (Figure 4.1), which has since been adapted into a cyclical life-cycle model (Figure 4.2), and to a somewhat less linear V-model (Figure 4.3).



Figures 4.1-4.3 (left to right): Waterfall design model, by Paul Smith; Life-cycle model, by Cliffydcw; V-model, by Herman Bruyninckx (all licensed for fair use via Creative Commons)

While differently organized, these design models have relatively similar components and stages. In a comparison of engineering design process models, Kilian Gericke and Luciënne Blessing found that the models shared a common set of stages: "Establishing a need, analysis of task, conceptual design, embodiment design, detailed design, implementation phase," with many including testing and iteration thereafter (2011, 9). This suggests a particular way of conceptualizing the design process into neat stages and cycles. The problem-solving activity essentially becomes: thinking, planning, making, trying, repeating.

This compartmentalization and schematic ordering of the design process reflects a particular theoretical approach to design that was common among participants. Take, for example, the agile development design methodology (Figure 4.4) used as part of the SCRUM project management system[11], and adopted at the technological institute GTS. Early document analysis of GTS's website showed multiple mentions of SCRUM and the agile methodology. During fieldwork interviews, participants used the methodology to explain their own design process:

> So we've tried to create a 'Product Owner', if you know that term. It's a project management term from a project management style called *SCRUM Agile Project Management*. Basically, what you do is you create a backlog of things that need to be done, a small story for each feature you need to integrate. And then there's a Product Owner who decides which feature to integrate first, and basically decides what the product should look like in the end. And in some cases, the Product Owner is the customer – so basically it's the one that orders the product, you can say. But in research and development you don't necessarily have a customer, but because you want to create a product for the customer, so someone needs to take the role as a customer. What would the customer need and what would they want? And decide, strategically, which features, and how should the system look – how should the product look – to the customer.
>
> (Software engineer)

Figure 4.4: "SCRUM/Agile Development as project methodology for the development of business software." (Niels Bering Larsen, 9 June 2011)

Like the design process models, the engineer's description of his institution's design strategy involves an ordered distribution of tasks. This description, however, is primarily theoretical and is laden with the terminology of the SCRUM methodology. The software engineer's description also points to particular values attached to the project management system and upheld by the software engineer. Here, decision-making is structured around the customer's needs, where decisions are made with respect to sales. GTS,

[11] www.scrum.org

however, is a research institute. The SCRUM methodology doesn't quite fit, as the software engineer subtly expressed: "But in research and development you don't necessarily have a customer...so someone needs to take the role as a customer." When pressed for narratives about actual decisions made according to SCRUM procedures, the engineers were unable to recall actual instances where the design proceeded according to the prescribed steps and with engineers fulfilling designated roles. The following exchange with a software engineer at GTS illustrates how he conceptualizes the design process through SCRUM discourse, even while inconsistent with the team's actual practices.

> There's a 'SCRUM Master', who is basically administering all of the – we call them stories. And there's the Product Owner that prioritizes stories. And then, of course, there's all of those exercising and realizing those stories. And the reason why they call it a story is that each story cannot take more than maybe a week to implement, so you have to limit the scope of the story. It has to be a very limited—so, something you as a developer can develop within a week, and tick-off. And you have to develop it fully. Because the trick of minimizing the result is you also finalize it completely. Often, if the result is very big, you don't finalize all the – you don't create the optimization, you don't create everything inside, you just make that it works in this one specific case. You don't really finish the code. And then, if it works, you don't go back to it. So the idea is that you make these very limited scopes, and then you finish the code, and you can check it off. And a story is usually, "As a user, I want to be able to start the robot by pushing this button." That could be, for example, a story.
>
> [*Is that an actual story, or is this a hypothetical one?*]
>
> That could be an actual story, but we have that button, so…
>
> [*Can you think of an actual story that has come up – in the graphical interface, or another one?*]
>
> We are not following this methodology of the SCRUM strictly. We should probably follow it more strictly than we do. But I think the concept is very nice and we try to use some of it. And I know that the guys doing the graphical interface are probably the guys that use it the most. So, in theory, the idea is that the methodology is very good. In practice, it requires someone who is very disciplined. It requires a SCRUM Master who is very disciplined in following up on that. And we're probably missing that stuff that we can integrate from those ideas.
>
> [*Do you have a SCRUM Master in this graphical interface?*]
>
> No, not really.
>
> [*But have some of them ever come to you with stories that you then have to prioritize? Has that happened already, or?]*
>
> I cannot—It has happened, but it's difficult for me to give you a concrete example.
>
> (Software engineer)

This difficulty connecting engineering thinking around the design plan to the actual activities within the design process seems to stem from a dissonance between the engineers' conceptual practices around design (i.e., his plans) and his material practices (actions). The SCRUM design methodology has permeated the engineer's language around design and decision-making, and has shaped the hierarchical structures of decision-making at GTS. The design plans are very clearly articulated within the framework of the design theory. However, the practices at GTS seem to be less explicitly aligned with the SCRUM methodology.

In one project, this particular software engineer has taken the role of Product Owner. When asked about how this role has shaped his work, he actually contradicted the SCRUM-defined roles and boundaries of decision-making.

> It happens all the time that they come and ask, "We have this thing – should we do it now? Should we wait? And how should it look?"
>
> [*Is there something they've come to you recently with, and you've said, "No, I don't think it's a priority"?*]
>
> Yes.
>
> [*Could you describe that?*]
>
> Yes, I think that happens often. We recently – actually yesterday, we did a release of the software. So there's been a lot of stuff until that. Of course, those realizing, they do a lot of the decisions themselves. If they are in doubt, "Should we focus on this? Or should we spend the resources on that?", then they ask.
>
> (Software engineer)

While in theory, the product owner should make these particular decisions, in practice, the decision-making is much more distributed. Nevertheless, the dominant institutional discourse around SCRUM is reflected in the engineer's descriptions and recollections of the design process. He was unable to recall a specific situation in which his theoretical approach to design was applied. So while certain design theories dominated his thinking around design, there was something different happening in his day-to-day practices.

STS scholar Lucy Suchman has examined this disjunction between theory and practice in her (1987, 2007) work on *situated plans and actions* among engineers and designers. She writes that "plans are best viewed as a weak resource for what is primarily ad hoc activity," (Suchman 2007, 26). In the HECHO project and other parallel projects at GTS, the detailed planning of design decisions through the SCRUM methodology was essentially ignored in the everyday design process (which *was* rather ad hoc); however, design plans were effective at restricting the design to a certain scope. While much of the *enactment* of the design was improvised, the practice of conceptualizing design in flow charts and in serial stages and engaging with particular design methodologies, theories, and plans, has nevertheless affected the engineers' orientation toward design, ultimately affecting many design decisions.

The engineers had a particular way of understanding and talking about the design process (*theoria*) that was often inconsistent with their other design practices (*praxis*) (J. A. Schmidt 2014). Their adherence to design philosophies and models might be representative of what I've thus far called 'engineering thinking'. Design processes were planned and perceived through prescriptive, compartmentalized, organized conceptions of design, such as the design process models already presented, but also in the SCRUM methodology which permeated the HECHO engineers' own recollections of their processes. As demonstrated in the previous interview excerpts, the engineers really struggled to recall their actual decision-making processes. This may be, in part, because these processes were rarely, if ever, as neat as the models. Their discourse-laden recollections did not seem to mesh with the behaviors and interactions I observed during the course of the fieldwork.

4.3 Pragmatic decision-making

Lucy Suchman maintains that "however planned, purposeful actions are inevitably situated actions…actions taken in the context of particular, concrete circumstances," (Suchman 2007, 26). While the HECHO engineers generally maintained the structured design plan, the engineers would often depart from these plans and their engineering thinking to engage in more organic negotiations of the design, reacting to new information, materials, and agreements to continuously make and amend design decisions. Although the word *decision* denotes a clear split from a state of singularity (indeed, the word derives from Latin *caedere*, meaning 'to cut off') and connotes an inherent reduction of possibilities, the decisions taken in the HECHO project were rarely clear cut.

During observations, these negotiation processes (with each other, with the materials, with the design plan) involved both rather explicit and more implicit decisions. The decision-making process sometimes involved different levels of action, such as: identifying uncertainty or disagreement, deciding to decide, deciding or agreeing, action or inaction, recognizing the completed action or revisiting the decision. Of course, these aspects of decisions were not always observed, and not necessarily in that order; nor were the decisions experienced or enacted in the same way by the different participants. This is just to say that a decision is not an abrupt shift in Cartesian status, from thought to action, but is generally much more fluid.

EXPLICIT DECISIONS

Richard Devon and Ibo van de Poel suggest that explicit decision moments are often built into the design process by project managers (2004, 466). In the case of the STACK project, which is funded by the EU, there are particular milestones written into the grant agreement. For example, the project members have agreed to make eight use cases, incorporating six particular modules for the robotic cell. The agreement, therefore, mandates decision-making moments wherein the members must decide which modules to include in each use case. The timing and order of this explicit decision is predetermined by the design plan in the grant proposal.

Other explicit design decisions are codified through design artefacts, such as the design process model for the DIEGO robotic cell (Figure 4.5). This model is tailored to the university's role and goal in the project, which was to develop a vision system (hardware) with optimized trajectories (software) for the robot's motions, so that the robot could detect an object and approach it with the optimum angles for picking it up (rather than manually programming the trajectory, and thus requiring the object to be in a fixed location for picking). As seen in the process model, each stage specifies decision-making moments, such as the selection of hardware. Less explicitly stated are the supporting decisions inherent to each stage, such as the type of objects to assemble, or the people assigned to model the hardware for simulation. (These more implicit decisions will be discussed more in the section that follows.)

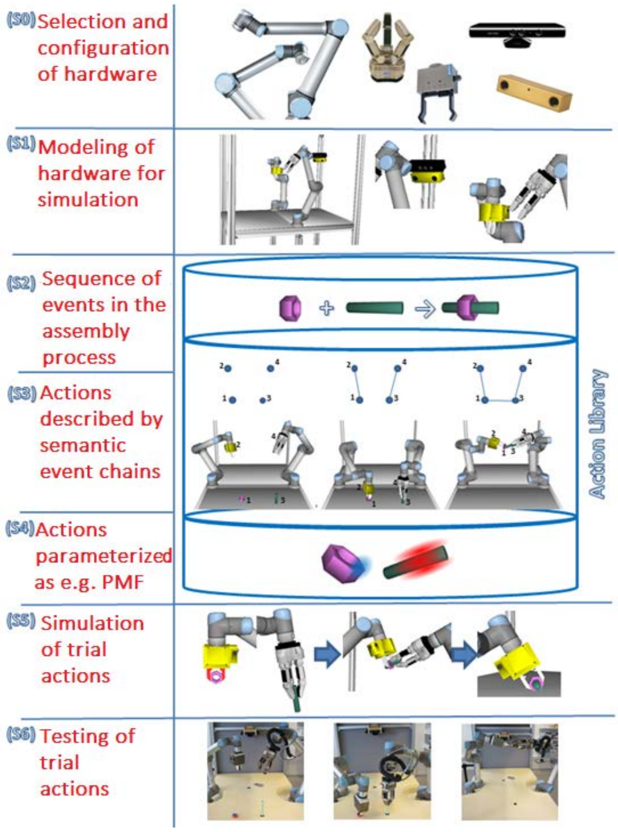


Figure 4.5: Robotics cell design process stages, taken from university website.

The design itself can also call for explicit decision-making moments, which are codified in the design artefacts produced. In the DIEGO project, the project members created specification sheets (Figure 4.6). These sheets illustrate explicit decisions already made (about the overall machine components and functions they have chosen to develop) but also presents the scope of the cell and options for particular functions More than that, these specification sheets, like the design plans shown in Figure 4.5, act as "devices that socially organize the workers, the work process, and the concepts workers manipulate in engineering design," (Henderson 1991, 452). In this flow chart, taken from the specification sheet, the robot's 'process skills' are specified. These are the tasks the robot will need to execute, which also breaks down functions into specific sections of coding/programming that the software engineers will need to develop. In this way, this artefact – termed '*inscription*' by Bruno Latour & Steve Woolgar (1986) or '*conscription device'* by Kathryn Henderson (1991) – has organized the decision-making activity of the engineers.

Take, for example, the "Pick" process skill. The flow chart shows the need for the robot to pick up a number of objects (solid items, foam parts, etc.). The chart then illustrates future decisions about whether the robot will pick parts from a random box, a standardized pallet, from a table, from another module, etc. Then, the chart leaves open the decision to pick them horizontally or vertically (designated paths), or by trajectory (optimized/adaptive paths).

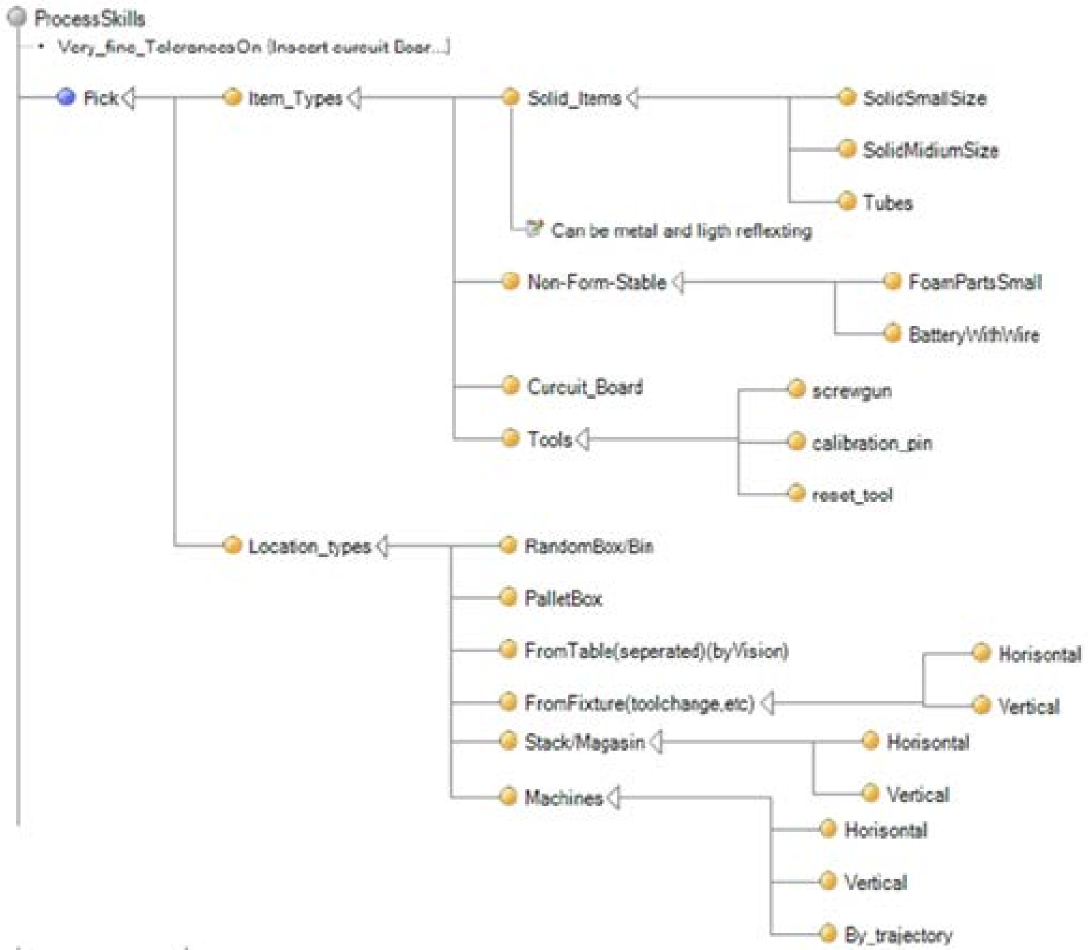


Figure 4.6: Flow chart taken from a specification sheet for the robotic cell CARMEN; provided by a participant.

The use of this design artefact further support the idea of engineering thinking around design processes, and the resulting planning of explicit decisions. Further, these two examples of inscriptions show that engineering thinking is not only a mental orientation (*theoria*), but is embodied in the material practices (*praxis*) of design planning. These engineering-thinking practices are not without consequence. Already, by breaking down the design process in such a way, and by specifying options, the design team has excluded other possibilities. Such early decisions tend to frame later decisions – or "organize the work processes" (Henderson 1991). As one participant described it:

> [*How much does the design change from the time you propose it to when something comes out in the end?*]
>
> Yeah, so usually the proposal sets the frame- you have to put it in and you have to paint the picture afterwards. And of course, that sometimes means that the frame has to be changed, but that doesn't happen that often. We try to keep it within the frame. And then if there is something new coming out of it, we see if there is somewhere else that we can pursue that direction.
>
> (Software engineer)

The software engineer explains his perception of the overall design as becoming relatively fixed during the [grant] proposal stage at the beginning of a project. He goes on to say that while there can be a great deal of flexibility in how the product is actualized, the final product rarely deviates significantly from the initial design. This idea of fixedness may be a result or a reflection of the way the engineers think about the design, as the execution of a plan, or solving a problem through designated stages: identification of a problem, formulation of a solution, development, and implementation. When engineers engage in engineering thinking and 'program' their design plans, applying what they already know about design theory to their ongoing design activities, they may constrain their own agency in subsequent design decision processes (Jacques Derrida 1989, in Steen 2015).

While this is mostly true for the big picture in the HECHO project (they did develop a "flexible user-friendly robot solution that enables rapid automation at low cost in small series production."[12]), many other design aspects (which processes to automate, vision system to use, e.g.) did change from proposal to implementation, and the HECHO cell continues to evolve under funding from a new project. Thus, the design isn't fixed by plans, neither is it finished, but is and there is still room for decision-making and ethical considerations. As Suchman (2007, 71; drawing on pragmatist George Herbert Mead 1934/2015) explains, plans are "representations of action" (*theoria*), whereas actions are situated, ad hoc improvisations (*praxis*). In the HECHO project, plans were found in the design artefacts and inscriptions around explicit decision-making, whereas action could be seen in the implicit decision-making of everyday design activity.

IMPLICIT DECISIONS

Most of the everyday decisions I observed were much less overt than those laid out in the design plans. From a pragmatic point of view, decision-making is both a conceptual (or theoretical) and bodily (or practical) process. A decision involves an anticipatory state before action is taken. For example, the group 'decided' to try new configuration for the standardized boxes from which parts are picked by the robot. The decision was formally made and acknowledged, however, the decided-upon action was never taken. Instead, the group awaited an alternative picking setup which relies on a new vision technology being imported from the United States. Thus, decisions might include the deliberate thought, the anticipatory orientation toward action, and the actual action or inaction (Simon 1967). Among the HECHO engineers, I observed particular moments in the dynamic process of decision-making, illustrated here by the decision-making

[12] A goal specified in the work package, under which HECHO is funded.

process surrounding the bolts and plates used to mount modules to the STACK workcell:

Identifying uncertainty or disagreement. The STACK cell was built upon existing technologies used or developed in the DIEGO and HECHO projects. These previous cells each had a custom-made tabletop set with a grid of threaded holes, 8mm across – based on the ISO standard M8 bolts frequently used to mount robotic arms. The team had wanted to create an iteration that offered more choice and freedom in placement. During a visit to ManuTech, a tabletop in the machine workshop caught the eye of one of the engineers from GTS. This tabletop was a Siegmund welding table top set with larger unthreaded holes.

Deciding to decide. The GTS engineer, whose primary motivation in the previous project had been to make the cell easy to reconfigure (both in terms of software and hardware), proposed the idea of building the new STACK cell with this tabletop. Modules would be mounted using fast-clamping bolts that are dropped into the unthreaded holes and hand-tightened, which would make for quicker and easier reconfiguration. The ManuTech engineer agreed to play around with the existing workshop table.

Deciding or agreeing. Eventually, the machine engineers decided to create an aluminum base that could be attached to the robot arm using standard M8 bolts, and mounted to the table using quick-change bolts. The result was a more efficient way to reconfigure the cell, meeting the goal of the GTS engineer. It also made the modules more "plug-and-play", which was a design goal for the ManuTech engineer. Not least, it was cheaper than the custom pallets they had previously created in-house. They agreed to move forward with the Siegmund tabletops in the design of the STACK cell.

Action or inaction. The engineers ordered the tabletops and integrated them into the new cells. This action toward the decision to use the tables involved creating bases for the robotic arms and building the bases of the modules to fit the layout of the table. The new component comes with new affordances (ability to join two cells together using mounting holes on the edges of the tabletops) and new constraints (inability to modify the table top or use threaded mounting hardware) (Gibson 1986). These constraints and affordances presented new problems – or, new decision-making opportunities.

Negotiating the completed action. During a subsequent status meeting, the production manager from Ingram asked about the change in the holes and the ManuTech engineer explained that quick-mounting modules make the cell more flexible. Ingram suggested they put a few fixed holes on the table, but ManuTech defended their decision to go with the new tabletop. They also explained how easy it would be to "dock" additional tables or units to the existing cell, using the fast-clamping bolts. Ultimately, Ingram agreed to the changes (it is Ingram who must pay for the hardware in this particular case) and the group decided to stand by their decision.

In this narrative, the collaborators proposed, discussed, agreed, tested, implemented, challenged, defended, and accepted the design decision. What this shows is that a design decision is not necessarily a cut-and-dry moment. Rather, a design decision is a *social process of negotiation* involving a pragmatic back and forth between consideration and action (see section 5.1). This process ought to offer room for ethical reflection and negotiation of values (see chapters 6 and 7).

While this design decision was materially about the tabletop, the quality underlying this decision-making process was *flexibility*. Flexibility is a key factor in the modularity of the HECHO and STACK cells. Returning to the HECHO project's goal to "develop flexible user friendly robot solutions that enable rapid automation at low cost in small series production," one can see how codified goals are sometimes translated into values in practice. This emphasis on flexibility was also present in the STACK project:

> Flexible Automation is the ability for a robotic system to be rapidly and easily reconfigured and re-tasked according to changes in a production. Enabling Flexible Automation by Robotic Automation Modules results in a situation where adjustment to – and changes in – a production are merely a matter of choosing and plugging in the right modules.[13]

Flexibility was enacted or demonstrated in a video by GTS where the modules are quickly recalibrated using GTS software (see section 5.2). Thus, this value comes through in both hardware (the tabletop) and software (the calibration function). The mechanical engineer primarily responsible for physically constructing the cells and machine parts at ManuTech has proclaimed, "I am in love with Apple!" The HECHO team aspires to create modular robotic cells which are as "plug-and-play" as Apple products are. The ManuTech engineer has stated that he wants the cells to be easy to use and intuitive, or "Apple-fied," as he put it. Likewise, his software counterpart at GTS has a goal to create plug-and-play software (like drivers) to go along with the hardware modules, which will be sold online in what he describes as an App Store equivalent for robotics. He, too, has an affinity for Apple: "When Apple made the iPhone, the most intelligent thing they made was not the phone itself, but the developer tools." Flexibility clearly guides their thinking about the cell's design and affects their decision-making practices. This is an example of a quality, or value, being engaged with in the design process and embedded into the robotic cell, both in explicit design plans (*theoria*) and through implicit design practices (*praxis*). With a mind to the EU's proposed regulation of robotics (which lays out potential effects of robotics on human dignity, autonomy, independence, health, wealth, companionship, and other human values), contrasted with the HECHO engineers' plain desire to "make cool robots, no matter what happens with them" I ask how it might be possible to extend this pragmatic practice of engaging with *functional* values (such as flexibility) to *human* values (such as dignity). I will unfold this question more in chapters 6 and 7.

4.4 Conclusion

In this chapter, I have argued that engineers are, first and foremost, problem-solvers. I have based this assertion on the word's origin, my own observations, and their own descriptions of their activities. Drawing on a pragmatist perspective (Lake 2015; Schmidt 2014; Dalsgaard 2014; Steen 2015), I've argued that design is a pragmatic problem-solving process, involving design plans in *theoria* and design activities in *praxis*. I have described what I call 'engineering thinking' – a theoretical orientation toward design which is reinforced by practices of diagramming design processes through schematic flow charts (Henderson 1991), and is made evident by reframing practical design activities through the discourse of particular design methodologies.

Continuing with the pragmatic perspective on design, I have considered how decision-making occurs through both *plans* and *actions* (Suchman 2007). I have argued that not only is engineering thinking reinforced by particular practices in conceptualizing the design process, but that engineering thinking affects the everyday decision-making that composes design activities. I have illustrated how engineers program the design process and how this schematic ordering of the design, sometimes through design artefacts or inscriptions (Henderson 1991, 2014; Latour & Woolgar 1986) constrains their everyday design activities by explicitly calling for design decisions at various moments in the design process.

[13] Taken from the STACK project website section on objectives.

I have presented a narrative illustrating the more typical implicit decision-making processes I observed. From this narrative, I have argued that design is a social process of negotiation involving a back and forth between consideration and action (Suchman 2007). I offer an example of a particular value successfully incorporated into the design, through both explicit plans and implicit actions. Finally, I argue that the design process offers room for the negotiation of values, which I will explore in chapters 6 and 7.

Thus, the HECHO engineers design decision-making was highly pragmatic, but also involved the social negotiation of the technical design. These social and pragmatic aspects of engineering design extend beyond the technical design with the negotiation of ideas and plans, to the engineers' negotiation of things like meaning, hierarchy, and identity through their material practices in the everyday interactions that compose the collaborative design process.

5. Sociomaterial Design Practices

In this chapter, I present design as a social process of negotiation. Design is inherently social, in that the engineers "come to their different design responsibilities with different perspectives, interests and expertise yet, at the same time, they share certain norms and common goals," (Bucciarelli 1988, 161). The decisions that engineers make are made within a particular sociomaterial assemblage –a constitutive entanglement of the social and the material (Orlikowski & Scott 2008). With an overarching interest in ethics and values in engineering, and a perspective of design as a social negotiation process, I turn to the *social ethics* approach which calls for "an examination of the social arrangements for making decisions that is particularly relevant to the iterative, decision-making, design process," (Devon & Van de Poel 2004, 461).

Through interviews and observations, I examined the structures, people, things, and places entangled in particular moments of decision-making in the HECHO and STACK projects. I found that the engineers' *social arrangements* (Devon & Van de Poel 2004) were kaleidoscopic processes of social negotiation in which diverse *object-worlds* (Bucciarelli 1988) were continuously colliding, being contested through *materially-mediated* decision-making processes (Suchman 2001; see section 5.2), and ultimately being rearranged into *new realities* (Law & Urry 2004) or *worlds* (Rapport & Overing 2002).

5.1 Social negotiations

Louis Bucciarelli argues that engineering design is a collective social process, organized around an object (1988). The social arrangement (Devon & Van de Poel 2004) organized around the HECHO cell was an interdisciplinary consortium of participants from five different organizations (as described in chapters 1 and 2). Each of the participants came with a particular set of experiences, identities, understandings, and interests influenced by their different workplace cultures, educational backgrounds, expertise, and roles in the project. Collectively, these diverse experiences entail different understandings and interests, which formed the engineers' *object-worlds* (Bucciarelli 1988, 161-2). These object-worlds acted as points of departure for engaging with the design through social negotiations. The engineers negotiated their understandings (learning a common language, for example) and their interests (like product development vs. research), through social decision-making practices around the cell as a *boundary object* in their interdisciplinary interactions (Henderson 2014; Suchman 2001). Across these negotiations of understandings and interests were also negotiations of decision-making agency. The result of these negotiations was the creation of new realities (Law & Urry 2004) in adapting existing object-worlds to form new understandings in the development of the robotic cells.

Negotiating understandings

The engineers' different understandings were reflected in the terminology they used to refer to the workcell. The engineers from GTS referred to the new cell as the "STACK cell," whereas the ManuTech engineers referred to the cell as the "Adapt Cell."[14] These different terms hint at the object-worlds the individual engineers are working from, and their divergent terminology also points toward the demands of

[14] Rather than search for the "right" term, I've had to acknowledge the significance of the different terms and their usage. For consistency, and because my fieldwork originated at GTS, I have adopted their terms 'STACK' to refer to the latest cell/project, 'HECHO' to refer to the previous cell/project, and 'DIEGO' to refer to the original flexible cell/project.

collaboration. The GTS engineers worked from the position of researcher-developers, understanding the cell as a research objective of their EU project, STACK. At ManuTech, however, the engineers were positioned as product developers; the cell was already being branded and sold as the product Adapt Cell, even as the STACK research continued. The Ingram team, a production engineer and a production/factory manager, referred to the cell simply as "the new cell," perhaps because this cell was simply the next automated production cell in a sequence of collaborations with the other HECHO partners.

Although the project members were each working within their own object-worlds, they collaborated across the same artefact, the cell, which acted as a boundary object (Henderson 1991), joining the diverse individuals and their unique fields of knowledge through a common affiliation. This working across boundaries of disciplinary and experiential knowledge required learning and negotiation. The engineers had to develop a common language, navigating jargon specific to their fields and workplaces. During a meeting held at ManuTech to practice programming new modules using the software GTS had developed, the project members landed in a tangential discussion of the term 'drivers'. The word had caused confusion during an explanation of the software. Again, working from their own object-worlds, the hardware developers at ManuTech understood drivers as *hardware* drivers, products one might download to ensure that an external device works with a computer. The software developers at GTS, however, used the term more generically to mean any bit of software that facilitates communication between two things (hardware, software, other drivers, etc.). The resulting discussion about drivers lasted the better part of a lunch hour, but the two groups eventually transcended boundaries of disciplinary knowledge in developing a common language about the object.

As the ethnographer, I, too, had to learn new terms, and how the different participants used and ascribed meaning to these terms, in order to understand what was happening in the field and to describe it. Working from my own object-world, which has been shaped by anthropology and philosophy of technology, I had understood 'processes' in a very general sense, hinting at the continuity of a behavior. In industrial robotics, however, a 'process' is a step in manufacturing – like faucet handle assembly in the production of faucets. A 'behavior' is a simple task a robot can perform – like *pick up handle*. This behavior is broken down into 'primitives' – a word best abolished from an ethnographer's vocabulary (Hsu 1964) but here meaning a basic command, such as *set position* or *open gripper*. As I progressed through the fieldwork, it was necessary to acquire and use this jargon in order to build rapport, interpret the engineers' work, and ask relevant questions (Berbary 2014). Thus, I had to negotiate understandings as my object-world met with the engineers'.

The interdisciplinary social arrangement in the HECHO team, and indeed my own involvement in it, presented certain challenges to existing understandings. What these anecdotes have shown is the effort that the engineers (and the ethnographer) exerted in starting from their own object-worlds and expertise, adapting to the new information their collaborators brought from their experiences, and ultimately developing a common language across object-worlds. Nelson Goodman (1984) has called this process of shifting realities '*world-making*'. This negotiation of understandings resulted in a common language about the material artefacts the engineers were collaborating around. It gave the collaborators a way to communicate their practices conceptually, to align their conceptions, and to create new shared understandings.[15] It is another example of the very social, pragmatic nature of the collaborative design

[15] For more on understanding the world through language, see texts on linguistic relativity (e.g., Whorf 1956).

process.

NEGOTIATING INTERESTS

Another aspect of the HECHO interdisciplinary collaboration is the negotiation of interests in design decisions. Once again, the project members enter negotiations from their own object-worlds, and must make shared decisions while balancing their various interests and motivations in the project. GTS endeavored to make a robotic cell that fit their research goals: an easily reconfigurable flexible cell, with an intuitive user interface for programming new processes. ManuTech sought to create a standardized, plug-and-play robotic cell and modules that they could sell as off-the-shelf products. Ingram wanted a workcell that would meet their production needs and fit with their existing equipment and deals with suppliers.

In the HECHO project, and especially in the STACK project, there was frequent tension between individual and project interests. At one status meeting, Ingram team members took issue with the PLC (programmable logic controller; i.e., computer) installed in the newest STACK cell, which was different from the controller that had been used in the HECHO project. Ingram had existing agreements with, and equipment from, Siemens that made it beneficial to continue to use their controllers. However, the GTS and ManuTech teams had fitted the new cells with PLCs made by Beckhoff, specifically for industrial automation. A Ingram factory manager was concerned that the old cells would have trouble communicating with the new cells, and said that they preferred that all Ingram factories use the same standard equipment and local databases. A ManuTech engineer argued against this:

> I am one hundred percent sure that this is just not the way we're going. It isn't the way that the industry will generally be going. And it isn't the way that new products are going to be.[16]
>
> (Robotics engineer)

When asked by another team member what he thought was the most "optimal and future-proof IoT [internet of things] setup," the same ManuTech engineer replied that each standard cell should have its own server and cloud database. However, he was tentative with his assertion using passive phrases such as:

> If I got permission to decide, then I would like to make an SQL server.[17]

The Ingram lead was less tentative and seemed to have trouble accepting their changed role in the project, saying, "There are also some things we shall have control of."[18] Previously, Ingram had been a customer requesting a custom piece of equipment. Now, they were both customer and development partner on a market product.

> The old HECHO cell, we designed that for the [faucet assembly] job. The new one we designed as a standard product, not necessarily for Ingram but for a bunch of other people as well, hopefully.
>
> [*Can you talk more specifically about the customer's needs versus what you want in a standard cell?*]
>
> Yeah, we had some discussions on that, because usually when Ingram buys a piece of

[16] Translated from Danish: "Jeg er hundred på, at det bare ikke er den vej vi går. Det er ikke den vej som industrien generalt komme til at gå. Og det er ikke den måde som nye produkter komme til at se ud på."
[17] Translated from Danish: "Hvis jeg fik lov til at bestemme, så ville jeg gerne lave en SQL server."
[18] Translated from Danish: "Der er også nogle ting, vi skal have styr på."

> automation equipment, they have some requirements to which components and which brands they use in their factory. So, for example, a lot of components in the STACK cell are *not* the brands that Ingram uses. So, if they have a machine built, they make these requirements to the machine-builder that it has to be components from Siemens, for example.
>
> [*And why would they do that?*]
>
> To be able to support them better, themselves. So that basically both in terms of support for themselves, that they are able to do some support themselves, and also in terms of spare parts and stuff like that. If one of the components breaks, they might have a spare part lying around or they have a deal with the supplier of those parts.
>
> [*Okay.*]
>
> So, this cell, it does not come with these parts as standard. We were trying to convince them that they should look at the product as a machine—a complete machine, you could say– not a combination of components.
>
> (Robotics engineer)

In previous projects, Ingram would put forth requirements, such as desired components from particular manufacturers, then ManuTech and GTS would customize the final cell to Ingram's specifications. However, the STACK project endeavors to make a finished product, with options for buyers, but not fully customized. This change in project goals and roles resulted in a shift in decision-making power (see next section on negotiating agency).

This interaction demonstrated how the engineers' selection of parts was tied to their own point of entry, or their own object-worlds. The ManuTech team members emphasized their controller choice as the more ubiquitous brand in the industry with more future-proof data storage options, better suited for the off-the-shelf product they're trying to develop. Again, ManuTech is following their own understanding of the cell as a product. Ingram, meanwhile, views the cell as a "piece of automation" - production machinery within their larger factory setup. All of the partners negotiated the decision of the controller with their own interests and points-of-view in mind, and their own understandings of the cell. This is an example of what Kathryn Henderson (2014) refers to as a *boundary object*; they each entered the negotiation from their own object-worlds, but worked across the boundaries of these worlds through the common object – the STACK cell. (See section 5.2 for more on boundary objects.)

NEGOTIATING AGENCY

Returning to Nickelsen's explanation of sociomateriality, and drawing on the example of the STACK controller, decision-making can be seen as a process of negotiation within a sociomaterial assemblage.

> From a sociomaterial perspective, agency is not simply someone's capacity to act, and cannot be defined as such a priori. On the contrary, agency is the capacity to act that is discovered and untangled by studying how sociomaterial assemblies and local truths emerge. (Nickelsen 2015, 7)

In such a process, the decision-makers are not equal or neutral actors with predetermined agency; rather, they negotiate their decision-making power within the particular context of the decision.

When the HECHO team transitioned from the HECHO project to the STACK project, the Ingram lead experienced a loss of decision-making agency. He was no longer in the position to dictate the brands and components he desired for his workcell. Instead, he would receive a standard product with a few customer options. Still, he was a part of the development team and would be partly responsible for determining the components integrated into the final standard cell. Throughout the status meeting, he returned to his role as customer, suggesting that he send a requirements list to the others for their input. This is important because of the way one ManuTech engineer explained decision-making in the HECHO project: the partner with the responsibility for realizing a particular task or feature would ultimately decide, but with "input" from the others.

> I can provide input in terms of the design, sparring partner, you could say, but I don't want to decide – it's completely up to them how to do that. They are the experts in the process. I give some input to the solution, but they basically decide how they want to do it.
>
> (Robotics engineer)

Another engineer, this time from GTS has put it this way:

> When you are new, you listen before you talk, but after a short while, then everyone – at least in this institution – says what they think. And then usually someone has to decide. And we've been very poor at—So we bring up a lot of ideas, everyone has their own, and then it often happens that the person executing the idea, realizing it, basically does whatever he wants—whatever he finds best.
>
> (Software engineer)

So, when the Ingram lead said, "We would like your input,"[19] he may have been implying primary decision-making power. This came through again when he suggested:

> But the first step is that we send our component list. And then it's given back, where you say, "These here, we will do another way."[20]
>
> (Factory manager)

He continued to suggest a back-and-forth negotiation process as though he were still the key client. This hierarchy he was leaning on came from the previous HECHO project, in which he was paying for all parts for a custom machine, and thus had significantly more decision-making power.

Another factor that affected decision-making agency was experience. As the software engineer above explained, the "new guy" usually just listens to those with more experience:

> When I started here I said, "For the first year or two, I just want to be told what to do, and I'll do it. And then that kind of evolved and now I have a bit more influence.
>
> (Software engineer)

> When you have a lot of experience, you are, of course, listened to. When you don't have as much experience, you listen to the others. And in this project, I was the new guy, so I had to listen to everybody.
>
> (Robotics engineer)

Generally, the more experienced players had more agency in decision-making. For an engineer at

[19] Translated from Danish: "Vi vil have jeres input."

[20] Translated from Danish: "Men først step, det er at vi sender lige vores komponentliste, som gives tilbage hvor I siger 'Det her skal vi laver på en anden måde,'."

ManuTech, this was sometimes problematic, in that he sometimes had to implement ideas that he knew wouldn't work, even against his "gut feeling."

> "When you're a new guy in the industry, you try to be humble….when you're a new guy in the consortium….I try to listen to everybody else, because I think they have been in this industry a lot longer than I have. So when I said, "I don't think this is going to work," they said, "At least we could try it out. It's not that expensive a solution." Of course, I said yes. I kind of-- it would be stupid not to.
>
> (Robotics engineer)

He explained that Ingram was paying for the HECHO cell and wanted to try the cheapest solutions first; ultimately, if they wanted to spend their money trying a solution, he had to go for it. These negotiations of agency demonstrate the situatedness of the design decisions (Suchman 2007). Decision-making agency was not fixed, but was shaped within a particular sociomaterial assemblage. Agency shifted with time and in relation to project roles – it was a part of the social negotiations of design.

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What these negotiations of understandings, interests, and agency show is that decision-making is a social process of negotiation. The result of these negotiations is the reconfiguration of the engineers' object-worlds and social arrangement. As the engineers interacted and shared experiences, their experiential approach to the object was altered to incorporate the new experiences and understandings. Thus, their object-worlds were always changing, forming *new realities* (Law & Urry 2004) as they interacted with others and with the design, in processes of *world-making* (Rapport & Overing 2002). Changes to their understandings affected their object-worlds, as did changes to the object itself. When the STACK cell became a standard product, the Ingram partner had to shift his understandings of himself and the cell.

This could be explained as a *relational ontology* (Barad 2003; Leonardi 2013), where nothing exists independently of its context or relation to other things/entities – or from a Heideggerian perspective, they co-constitute each other. In this case, the robot is defined in relation to the experiences of the persons defining it. Ingram production engineers understood the cell in relation to production processes at the factory, whereas the GTS engineers understood the cell in relation to their research. Their object-worlds were defined by the interests and research goals surrounding the cell. Finally, the ManuTech engineers understood the cell in relation to company goals and an affinity toward Apple's design, strongly reflecting the functional value of *flexibility*. The engineers' approaches to the cell's design were both afforded and constrained by their experiences in other projects, by their disciplinary knowledge, by the social arrangement within the project, and not least, by design materials.

5.2 Material mediations

The social negotiations of engineering design are material practices. From a sociomaterial perspective of relational ontology, the social and the material cannot be separated. Sociality is built upon material interactions – we exist within a material world and we ourselves are material. Materiality is also inherently social as materials are defined by, and shape, their social context (Ihde 2009; Roehl 2012). Engineering design may be particularly material in that it involves practices of crafting material artefacts. This section, however, examines the material aspects of decision-making, describing how social negotiations are materially mediated. Tobias Roehl (2012) writes that "material objects are indeed treated as mediators – they mediate human experience and existence by transforming human perception and action," (54). The design artefacts the HECHO engineers used shaped both their understandings and their activities within the social negotiations of the design process. This pragmatic mediation is apparent in how design artefacts as *conscription devices* (Henderson 1991) were used to organize work and formalize decision-making; how particular uses of artefacts revealed something about power and intentions; how material artefacts like the robotic cell were *multistable,* defined by their social context (Hasse 2013; Roehl 2012; Ihde 2009).

Lucy Suchman (2001) argues that the tools of engineering (such as CAD or sketches) can be *mediating devices* for imagining future technologies (168). In the HECHO and STACK projects, specification sheets, conceptual drawings, promotional videos, and organizational documents projected onto screens codified the participants' plans and visions for the robotic cells and their components, but also contributed to the actions taken toward realizing these plans. To illustrate these processes of material mediation, I turn to a STACK status meeting held in November at GTS.

The meeting was held a conference room off of the "innovation" hall at GTS. The innovation hall is a two- to three-story hall with floor-to-ceiling windows. When approaching the building from the parking lot, there is a clear view of robots on display. It is essentially an exhibition hall, but is also where the local start-up hub is hosted - therefore, some actual building and testing does occur here (but the real workshop is closed-off elsewhere in the building). Inside this hall is a meeting room, sectioned off by its own glass walls. The room is set up with a long and very broad conference table, with six chairs alongside each long edge. At one end of the table is a large screen. This end of the table was set with bread and coffee, suggesting the entire table would not be used. When I entered the room, Mikkel,[21] a technical manager for an Ingram factory, was already seated at the table, near the screen, joined shortly thereafter by his process engineer, Sam. Søren, a software and robotics engineer from GTS arrived with Henrik and Emil, process and mechanical engineers from ManuTech. They seated themselves across from the Ingram party while I positioned myself further down the table so that I could take notes and observe less conspicuously. Everyone chatted amiably until Gustav, a software and robotics engineer from GTS arrived. He moved a chair to the head of the table, nearest the screen, and called the meeting to order. Gustav is the STACK project manager, and was therefore hosting this meeting. He opened his laptop and projected it onto the larger screen, displaying a document containing the day's agenda. Gustav had positioned himself as the meeting's leader, by taking a seat at the head of the table and by controlling the screen (and thus the day's proceedings).

PROJECTION SCREEN

Gustav (GTS) had laid out the agenda on the projection screen, to which everyone's attention was directed. He was pointing at the screen as they went through the first presentations. The day's agenda was to open with a round of status updates, followed by a demonstration of the GTS cell, before discussing current and future tasks. Gustav was taking notes within the agenda document – defining what was important by writing it down. He also made and shared a video (see section on video presentation) that demonstrated GTS's latest work on the project. The projection screen served as an *conscription device* that organized the work process (Henderson 1991, 452). The screen was where they collectively summarized, organized their decisions, current and future activities. For example, the agenda had organized the morning's activities and identified the particular members who would lead each activity:

1) Status (All)
2) Presentation of Adapt Cell (Emil)

[21] Although permission has been granted to use the engineers' names, I have used pseudonyms for reasonable privacy.

3) Demo using demonstration cell [22]

Although the agenda organized the work of the entire group, Gustav alone controlled the computer, the screen, the organization, the order – and thus the meeting. Tobias Roehl, working from a postphenomenological perspective, has written on how a blackboard mediates interactions between a physics teacher writing on the board and the students gazing at the board: "The teacher serves as a gatekeeper of what is deemed worthy of recording on its surface and is hence turned into relevant knowledge," (Roehl 2012, 63). Likewise, Gustav was the gatekeeper of the projection screen, the agenda, and the activities it (he) organized. This material artefact and the sociomaterial arrangement of the space – with Gustav at the head of the table and ManuTech (the sellers) positioned across the table from Ingram (the buyers) – contributed to a particular power dynamic in which Gustav was in charge, but was also the referee in the negotiation process to come, between Ingram and ManuTech.

Although Gustav led the meeting, it became clear in the first hour that the group was anticipating a decision by the Ingram team (as partner, but also as customer). The two other partners present, GTS and ManuTech, were to give status updates and demonstrations of the robotic cells located in GTS's other hall. Mikkel (Ingram) asked questions throughout while his colleague Sam looked on and the remaining meeting participants answered Mikkel or observed. It seemed as though Gustav (GTS), Emil, and Henrik (ManuTech) were trying to sell Mikkel (Ingram) on the new cells. In a later interview, Gustav clarified, "Yeah, so ManuTech was trying to convince Ingram to buy their new standard product, you could say." This role of buyer was a shift from Mikkel's previous position in the HECHO project, where he was purchasing custom equipment. Likewise, ManuTech had taken on the role of a product manufacturer, in addition to their role as system integrator. Despite Gustav heading the project and the meeting, Mikkel having the deciding power at this particular meeting may have contributed to a power shift that occurred when Mikkel disrupted the interaction order and the agenda and insisted on moving things around (see section on posters). Gustav adjusted the agenda on the projection screen, moving cell demo (item 3, above) ahead of the presentation of the Adapt Cell (item 2, above). This on-screen change to the agenda validated Mikkel's demand and his challenge to the meeting's asymmetrical social arrangement (Kalthoff & Roehl 2011).

This was not the only use of the projection screen to organize and prioritize the group's ideas and actions. Toward the end of the status meeting (after some time looking at the actual workcells), the group returned to the table and to the projection screen. Gustav, again acting as gatekeeper, reformed the agenda items to minutes, changing bullet points to past tense statements, such as "Emil presented Adapt Cell." Now, the agenda which had organized their future activities for this particular day, became a record of completed activities, but also an organizer of current and future activities. The agenda was reorganized under three major categories:

1) Status
2) Current plan
3) Long-term [23]

Under current plan, he listed everything that had been decided, such as: "(Ingram) sends their component

[22] Translated from Danish: "Status (Alle); Præsentation af Adapt Cell (Emil); Demo ved demonstrar cellen)"

[23] Translated from Danish: "Status; Nuværende plan; Fremadrettet"

list; (ManuTech) answers back with alternatives, and why."[24] This example was a decision to decide about which components to include in the new STACK cell (primarily concerning the Siemens-Beckhoff controller), with action items (send list, answer back). When the discussion returned to the issue of the controller, the group agreed that Henrik of ManuTech and Mikkel of Ingram should have a meeting about it. So, Gustav wrote: "Meeting (ManuTech and Ingram)."[25] Here, we can see how the agenda was used to organize future decision-making.

Throughout the meeting, although the members might be using politely passive language that made decision-making agency unclear, such as: "If I got permission to decide… I think… We want your input… I would really like… In principal...," the verbal language used when assigning tasks inputting names into the agenda-minutes document was much more matter-of-fact: "We decide this… Me… You… Ingram… ManuTech…"[26] Thus, the act of collectively defining the "current plan" and the "long-term" involved a shift from negotiation and uncertainty to certainty – even if the decisions and tasks were simply deciding to decide. In transforming plans into agenda items and minutes on the projection screen, these decisions or plans became formalized into an artefact or conscription device which might later organize or direct the group's behavior (Kalthoff & Roehl 2011; Suchman 2007).

Thus, the use of a projection screen, of a working agenda and meeting minutes, organizes work, makes clear the social arrangement, and formalizes the distribution of decision-making agency around particular design tasks.

POSTERS

Whereas the projection screen worked as an conscription device which organized the activities around decision-making, during the same meeting, conceptual drawings were used in another way - unsuccessfully as representations of the new Adapt Cell (or, STACK cell). As part of ManuTech's status update, they had prepared conceptual drawings to present to Ingram. For ManuTech, these images represented the Adapt Cell, a product they are trying to build and bring to market. These drawings were polished advertisements directed specifically at end users (customers). Unlike the technical drawings used in the HECHO project, these lacked schematic details that highlighted connections, sizes, placement, function, etc. Instead of skeletal sketches, printed on a single sheet of A4 paper, the conceptual images were printed in color, with a single image stretching across a large sheet of A3 paper, to create a poster-like product. Emil (ManuTech) delicately unfolded the posters, smoothing the fold lines, and slid them across the conference table to Mikkel and Sam (Ingram).

The posters contained computer-generated images or models of the cell against a white background, presented from different visual orientations. The posters lacked the three-dimensional detail, moving parts, and scale of the robotic cell. The robotic cell depicted in the images did not show trailing cords bound in plastic zip ties, or the various screws, stickers, and wires visible on the attached industrial robot arm. Neither did they show the various people and artefacts necessary for the robotic cell to perform (manufacturing parts, operators, transport trays, a mobile robot interactant, etc.). Tim Ingold (2010) makes a distinction

[24] Translated from Danish: "(Ingram) sender deres komponentliste. – (ManuTech) svarer tilbage med alternativer, og hvorfor."

[25] Translated from Danish: "Møde (ManuTech og Ingram)"

[26] Translated from Danish: "Hvis jeg fik lov til at bestemme…Jeg synes…Vi vil have jeres input…Jeg vil vildt gerne…I princippet…"; "Det bestemmer vi…Mig….Jer…Ingram…ManuTech…"

between the *object* and the *thing*. The images printed on the posters represented the Adapt Cell as an object, separate from its context as a fixed and independent artefact. The robotic cell as a thing, on the other hand, is a changing material artefact embedded in a particular context. Whereas the thing is an ongoing amalgamation of the material and its interactions with other things and beings, the object is the sterile view of this entangled thing existing in isolation (Ingold 2010). The images of the Adapt Cell were objectified representations, obscuring the thingness of the machine in context.

As Mikkel examined the drawings, Emil began his presentation of the Adapt Cell, explaining some of the changes the ManuTech team had recently made to the cell. In the middle of Emil's explanation of the new tabletop and fast-clamping bolts (see section 4.3), Mikkel interrupted and said that none of this would make sense until he'd seen the cell in action.

> Mikkel: Shouldn't we go out and look at them?
>
> Emil: Yes. We will soon.
>
> Mikkel: I'm thinking – honestly – isn't it more practical if I stand and look at it and get my hands on it? [27]

For Mikkel, the drawings were not sufficient representations of the machine itself. They didn't fulfill the mediating task intended – they couldn't bridge concept and materiality. This failure might be attributed to the posters' physical characteristics – their objectness; it may also be attributed to a failure to engage with the posters' performative properties.

Design artefacts are relational objects – they do not do the same work alone that they do with human interaction (Heidegger 2008/1927; Suchman 2001). It is the interaction which essentially pulls them into a particular context and brings them to life. As *inscriptions*, these drawings lose meaning when removed from their context- the meaning is socially constructed, so a change in the social arrangement means a new translation or negotiation of meaning (Latour & Woolgar 1986; Henderson 2014, 1991; Johri, Roth, & Olds 2013). The posters, without the physical properties necessary to bridge the conceptual-material gap, and without the familiarity with the actual cell necessary to interpret them, they required some performance on Emil's part to fulfill the task of representation. Emil had laid the posters in front of Mikkel and Sam, leaving them flat and unanimated, neglecting the performative aspects of the artefacts. Take, in juxtaposition, the case of an engineer presenting CAD drawings, which Lucy Suchman describes:

> We should note as well the performative aspects of the lead engineer's relation even to the objects of computer-aided design in the course of her tutorial. For example, she makes continuous use of what Goodwin (1994) has named "highlighting for perception," instructing us on where and how to look with the gestures of her pen on the screen. Her gestures add a kind of third dimension to the CAD screen as when, for example, she is describing the slope of a road. And her gestures animate the CAD image. So, for example, once she has used the system to create a series of cross-sections of a roadway, say every five or twenty meters, she can then effectively "travel" along the roadway by scrolling through the sections. (2001, 170)

The engineer in Suchman's description points and scrolls, drawing attention to particular paths and slopes, and engaging with the other engineers' imaginations. In contrast, Emil left the posters to do work that they

[27] Translated from Danish: Mikkel: "Skal vi ikke ud og kigge på den?" Emil: "Jo. Det skal vi snart." Mikkel: "Jeg tænker -helt ærligt- er det ikke mere praktisk at jeg står og kigger på det og stikker fingerne i?"

were not equipped to do alone, resulting in inadequate representation, resulting in Mikkel's demand to see the product. Gustav made the adjustment to the agenda while the group halted the status updates and instead prepared to move from the conference room to the demonstration hall to see a similar cell in action.

VIDEO PRESENTATION

While Gustav set up the robotic cell demonstration, Søren (GTS) showed a video that GTS had made for the STACK project, entitled "Identification and Inter-module Calibration", which showed how easy it would be for end users to recalibrate modules after installing them on the table of the robotic cell. In the video, Gustav sets a physical place-marker in the grid of the cell's table, then moves the robotic arm to meet the place-marker and selects "teach this position" on the Universal Robot touch-screen interface. It showed a screen capture of the manual input of the coordinates into GTS's software. Many waypoints and several modules were calibrated or re-calibrated in the video. The video itself was under 5 minutes long and was not a continuous cut. It had a promotional air that didn't reflect the challenges, testing, and tweaking that I'd witnessed during the calibration in the lab just a few weeks prior. In that visit to ManuTech, Gustav had worked with another GTS engineer to manually set the waypoints, with one moving the arm to a position, bending to check the gripper's position at eye level, and the other typing in the corresponding numerical positions, in a call-and-response choreography. The video presented a very different scene, in which the calibration process was completed gracefully and easily by Gustav on his own. Like the posters, the imagery in the video was too neat – an obfuscation of contextual details.

It was during this video demonstration and in the subsequent demonstration of the robotic cell, that it became clear that ManuTech and GTS were trying to sell Ingram on the latest iteration of their modular robotic cell. This status meeting was an opportunity for GTS and ManuTech to justify their design choices to each other and to Ingram (the buyer) and to plan for the next steps in the product's design. In understanding the intentions of the participants, it became easier to understand their use of the design artefacts. In contrast to their use of images made for the practical or technical purposes of design, such as the specification sheets, which were created to open up the design, revealing hidden details, like an anatomical drawing, the images made as advertisements (i.e., the posters and the video) were created to dazzle and mystify, concealing the inner workings of the machine—"Apple-fied". These different artefacts were made and interpreted with different intentions (Dant 2004) and from different object-worlds (Bucciarelli 1988), used in accordance to the project members' different motivations: to sell and to scrutinize. These motivations became more apparent when the participants were all engaged with the same material cell during the demonstration.

DEMONSTRATION CELL

The robotic cell on display was one of the STACK project cells - not the Adapt Cell being produced at ManuTech as a market product, but another cell built from the same base construction as the Adapt Cell, but further developed and adapted by GTS for research and demonstration purposes (with the cooperation of ManuTech and the other consortium partners). One week prior, GTS had hosted an event, so the demonstration cell had been recently exhibited. It had been programmed to perform various tasks, demonstrating its diverse abilities; however, the robots weren't actually going through real production processes, but were performing a repetitive ballet: pick, place, replace…pick, place, replace…repeat.

The robotic cell demonstration at the November status meeting was drastically different from what I'd observed in October during a development meeting. In contrast to the Adapt Cell in the electronics workshop at ManuTech, the demonstration cell had its safety system enabled. The demo was started with everyone standing behind a safety line. Gustav prompted the consortium members to approach the robot, triggering its safety system. The LED light panels installed along the vertical corner edges of the cell blinked red because the project members were standing within a specified distance from the sensors. As Mikkel and Sam (Ingram) examined the cell, the lights continued to flash. During my previous encounter with the Adapt Cell at ManuTech, they had reduced the sensor's detection distance to a few centimeters, so that the ManuTech and GTS engineers could work closely with the machine without triggering the safety system. Although the examination of the demonstration cell lasted for an hour, the system remained engaged. GTS could easily have demonstrated the safety capabilities and then disabled it, as they did for me at ManuTech - the flashing light was certainly disturbing enough to warrant it – however, they did not.

As with the posters and the video presentation, this demonstration was a sort of performance that was not instrumental in the design of the cell, but rather in gaining Ingram's approval and in selling the cell. This incident illustrated the motivations behind the status meeting, which were to sell the cell. What began as a group demonstration quickly broke down into smaller negotiations, including the Siemens-Beckhoff discussion (see section 5.1). These episodes illustrate the *relationality* or *multistability* (Ihde 1990) of the cell. The cell is not a stable artefact, but a technology-in-use, defined by the interactions with and around it. In October, the engineers were troubleshooting a cell in development – it was a design project between GTS and ManuTech, a boundary object (Henderson 1991). Even as they understood it differently within their own object-worlds (a product at ManuTech and a research project at GTS), they shared the common goal of developing the cell. With a change in context, still involving the same project members from GTS and ManuTech, but with different motivations and additional actors, the cell became instead a marketed product. The ontology of the cell itself was shaped by the sociomaterial assemblage in which it was embedded.

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These narratives from one particular day amongst the engineers demonstrate how the social negotiations of decision-making and design were materially mediated in the STACK project. The projection screen and the agenda/minutes formalized certain aspects of the social arrangement, such as the division of labor, and served as conscription device organizing the group's past, present, and future behavior. The conceptual posters did not successfully represent the robotic cell, which points to the importance of the performative aspects of inscriptions, but also points to how the engineers' translation of artefacts is tied to their understandings and interests, or object-worlds. Finally, the robotic cell showed how a design artefact can be multistable, dependent upon the context and motivations of the engineer. The same object was performed and interpreted differently with regard to shifts in the sociomaterial assemblage. These artefacts and the negotiations they supported revealed something about the engineers' object-worlds, but also assisted in altering their object-worlds, and the cell itself—ultimately forming new realities (Law & Urry 2004).

5.3 Conclusion

Working from a sociomaterial perspective into design, I have presented narratives from fieldwork among the HECHO engineers to illustrate the social negotiations that make up the collaborative design processes, and the material artefacts which mediate the decision-making activities among the engineers.

The everyday pragmatic design work in this collaborative project took shape through social negotiations of understandings, interests, and agency, influenced by engineers' existing object-worlds and social arrangements, and organized around the robotic cell as a boundary object. These worlds were reformed and rearranged as engineers incorporated new understandings and interests, in processes of world-making.

The material artefacts the engineers used in their design and decision-making practices played a part in shaping the engineers' understandings (conceptions) *and* their negotiation activities (actions) within the sociomaterial assemblage of the STACK project. The use of design artefacts organized their work and made clear particular social arrangements, decision-making agency, motivations, and understandings. These materially-mediated social negotiations were the everyday design interactions in which decision-making occurred.

As demonstrated by the HECHO engineers' work, design is not fixed. Design is a complex and dynamic social process. Object-worlds evolve, and understandings and interests evolve. At the intersection of these different object-worlds is a social process of negotiation and consensus, a consensus somewhat awkwardly expressed in the final product. When object-worlds collide – new realities are formed through learning processes of negotiation and material practices that transform existing understandings and orientations. This iterative process of design discovery is what Horst Rittel & Melvin Webber (1973) termed a 'wicked problem'. [28] These continuously developing sociomaterial realities make it problematic to address ethics only in the earliest stages of design, as the engineers have been wont to do (see section 6.2).

[28] For more on wicked problems, see Lake 2015; Buchanan 1992; Rittel & Webber 1973.

6. Engineering Ethics

Collaborative engineering design is dynamic, not fixed. As design decisions are continuously negotiated, the design is transformed, but so are the actors as their object-worlds are transformed in the social processes of negotiation. If this is the case, how are ethical considerations incorporated in such a fluid design process? If engineers are indeed creating new realities, how is it possible to consider ethics and to embed values in design, to create ethical new realities?

In the following chapter, I examine existing attempts to embed ethics in engineering that have missed the mark. Then, I present how the HECHO engineers talked about and understood ethics, and how they incorporated particular values into their work. These empirical findings suggest a need for a pragmatic and social engineering ethics that includes the *negotiation of values* in design, and, perhaps a role for ethnographers in shaping ethical realities.

6.1 Formal engineering ethics

Returning to the motivation for this thesis – the EU Parliament's (2017) resolution, Civil Law Rules on Robotics – I turn now to previous regulatory efforts toward ethics in engineering design. Existing engineering ethics approaches have been neither pragmatic nor social – even while engineering design is (as demonstrated by the HECHO engineers). From a review of engineering and design literature and organizational documents, I have found that formalized attempts to instill ethics into engineering activities have been prescriptive and narrowly focused on the individual engineer. Like engineering design plans, approaches to engineering ethics have been similarly schematic and ordered – not like the more dynamic and pragmatic negotiations observed amongst the engineers.

Engineering ethics emerged as a field in the 1970s (Weil 1984), but really burst onto the scene in the mid-1980s after the Challenger space shuttle disaster – a case which remains a pet example in engineering ethics today (See, for example, Rossow 2012). The Challenger space shuttle, launched in the United States, exploded before even leaving the stratosphere, due to a known engineering vulnerability and the decision to proceed with the launch despite engineers' objections. The explosion, televised live, caused a devastating loss of life and was a national disaster in the United States, resulting in multiple investigations, public hearings, and a broad call for attention to ethics in engineering.

From the ashes of the Challenger rose professional codes of ethics, oaths, edicts, filled with principles, canons, and the like –targeted at the engineer's professional conduct (Davis 1991; American Society of Civil Engineers 2011). These codes of conduct have been based on situations like the Challenger, in which there occurs a conflict between an engineer's personal morality and structural elements, such as cultural pressures or hierarchical decisions – what Ronald Lynch and William Kline term "whistle-blowing" cases (2000). These approaches, with an overly narrow focus on such David-and-Goliath, make-or-break situations overemphasize big decisions, major risks, and – most importantly – the onus on the individual engineer. Such an engineering ethics combines aspects of deontological, consequential, and virtue ethics, wherein the engineers' adherence is dependent on rules, consequences, and moral character, respectively (Furey 2017).

Codes and oaths which target the individual engineer's moral compass attempt to affect a person's ethical thinking or orientation rather than their everyday practices and the structures in which they're embedded. For example, the Institute of Electrical and Electronics Engineers (IEEE), a major international professional association for robotics engineers, has the following canon under its code of ethics:

> We, the members of the IEEE […] agree: to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment. (IEEE 2018)

The American Society of Civil Engineers' (ASCE) nearly identical canon reads:

> Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties. (ASCE 2017)

Again, the canon is found, simplified, in the National Society of Professional Engineers' (NSPE) code:

> Engineers shall hold paramount the safety, health, and welfare of the public. (NSPE 2007)

These aims are not all that actionable; holding something paramount amounts to a feeling or an orientation – not a practice, and not an organization's social arrangement. The ASCE code of ethics, however, also contains "guidelines to practice under the fundamental canons of ethics," which seem to be the operational guidelines for each moral canon. For the aforementioned ASCE canon, one guideline reads:

> Engineers shall recognize that the lives, safety, health and welfare of the general public are dependent upon engineering judgments, decisions and practices incorporated into structures, machines, products, processes and devices. (ASCE 2017)

For a practicable guideline, it seems difficult to enact the verb "recognize" – a word which points more to a mental activity than a material or practical one. The other guidelines for both the ASCE's and the IEEE's codes of ethics are directed at whistle-blowing prescriptions, declarations against fraud and discrimination, and tenets such as "be honest and realistic" (IEEE 2018) or "be dignified and modest" (ASCE 2017). In a 2011 review of engineering organizations' codes of ethics, the American Association of Engineering Societies (AAES) found many similarities (as demonstrated above). These professional organizations have in common a focus on the virtuous engineer who subscribes to particular moral principles and behaves according to prescribed norms.

These professional edicts have dominated engineering ethics from their inception.[29] This period is marked by a neglect of collective decision-making processes, pragmatic everyday decision-making activities, and the cultural and social factors in these processes (Lynch & Kline 2000; Herkert 2005). Recently, there has been a push away from rule-based deontological and consequential ethics (Furey 2017). Faith in such approaches has fallen, as there has been a noted failure to produce 'good engineers' or 'moral experts' (Schmidt 2014; Furey 2017). Consequentially, there have been arguments for a more virtue-based engineering ethics, relying more on an engineering morality rather than rules or oaths about right and wrong. While a move away from deontology is in order, I argue that it ought to be a move toward *pragmatic* ethics, and not toward virtue ethics. Overall, virtue ethics relies too heavily on theory and ethical thinking, and not enough on the praxis that *is* engineering.

In line with this attitude, there have been calls for a professional engineering ethics that does pay attention to everyday practices, to target the ethical decision-making behaviors of engineers (Martin & Schinzinger

[29] See, for example: ASCE https://www.asce.org/ethics/; IEEE https://www.ieee.org/about/corporate/governance/p7-8.html; ACM https://www.acm.org/about-acm/acm-code-of-ethics-and-professional-conduct?searchterm=code+of+ethics; NSPE https://www.nspe.org/resources/ethics/code-ethics; WFEO http://www.wfeo.org/ethics/.

1996; Lynch & Kline 2000; Manning 2003; Swierstra & Jelsma 2006). Nevertheless, new and continuing efforts at formalized engineering ethics still center on ethical orientation, and professional conduct, through edicts, codes of ethics, and regulations (Hess & Fore 2017). Harking back to the EU's recent resolution to govern robotics (European Parliament 2017), top-down measures with nondescript goals were once again proposed:

> [W]hereas the Union could play an essential role in establishing establishing basic ethical principles to be respected in the development, programming and use of robots and AI and in the incorporation of such principles into Union regulations and codes of conduct, with the aim of shaping the technological revolution so that it serves humanity and so that the benefits of advanced robotics and AI are broadly shared, while as far as possible avoiding potential pitfalls. (European Parliament 2017)

The EU parliament further suggests:

> A framework in the form of a charter consisting of a code of conduct for robotics engineers, of a code for research ethics committees when reviewing robotics protocols and of model licences for designers and users…based on the principles of beneficence, non-maleficence, autonomy and justice. (European Parliament 2017)

With the European Commission's concurrent investment of 700 million euros in robotics research and development,[30] and diverse concerns about the growing implementation of robotics (TNS Opinion & Social 2012), the moment is right for reconsidering the traditional deontological or virtue-based approaches which have thus far been unsuccessful (Schmidt 2014; Furey 2017; Gert 2009). I suggest departure from hypothetical, procedural frameworks that target the engineers' moral reasoning, and a shift instead to incorporating human values into the pragmatic design activities of engineers that have been depicted in this ethnographic study.

6.2 EVERYDAY ENGINEERING ETHICS

The HECHO engineers approached ethics theoretically, rarely (if ever) engaging with ethics in practice. Just as design models were entangled with the engineers' thinking about design (see section 4.2), the way the engineers conceptualized and experienced ethics was consistent with the prescriptive commands of the professional codes that govern engineering and with the procedural logic that permeated engineering design theory. In interviews, most of the participants expressed a sense of morality and empathy, but did not locate ethics within their own design practices. After sharing some narratives about ethical consequences of implementation, the engineers began to understand ethics in a new way and could identify ethical issues within their own projects. Nevertheless, they either felt it was not *their* responsibility to account for these ethical issues in the design process, or that their ethical decisions were constrained by the design plan, by hierarchy, or by the customer.

ETHICS DO NOT APPLY HERE

One robotics engineer, responsible for overseeing all robot development at GTS, did not think ethics was relevant to the design of industrial robotic cells at all.

> If you want to look at ethics, you won't find it here [industrial robotics]. That's one of those things you mark off---not relevant [miming a checkmark]. Nobody here is working

[30] SPARC/euRobotics https://www.eu-robotics.net/sparc/about/index.html

> on ethics.
>
> (Robotics engineer)

He held that safety regulations and CE markings served as the markers of ethical design in industrial robotics, saying that if you design within these parameters, your machine would be ethical. Other engineers also equated ethics with physical safety, but not with other forms of well-being, like emotional or social welfare.

> What we're considering, mainly, is: Is it safe to use? ...The one issue is safety. If there is something safety-related, we have to change it. And we do. We consider that very deeply.
>
> (Software engineer)

Many of the engineers shared the opinion that ethics was important, but that it was not a part of their work to consider the ethical aspects of the design.

> I think things like pride and social interaction are not part of what we're considering.
>
> (Robotics engineer)
>
> Funny, I never thought of these issues much before.
>
> (Software & robotics engineer)
>
> Technical people are not involved in things like that.
>
> (Automation consultant)

The very nature of engineering, their problem-solving orientation, was often used against ethical thinking. This thinking presumes that the technical and the ethical aspects are separate, and that ethics is *not* a part of engineering.

> We're just trying to solve a technical problem.
>
> (Software engineer)
>
> I think, for most of those, actually physically building the solutions, their motivation is the technical aspects. *We just want to make cool robots, no matter what happens with them* [emphasis added]. And cool solutions. Whereas, I think that most companies would also be run by people who just want to make cool solutions for people….Yeah, so there's a difference in those making a robot, building it, and those actually using it….I'm sure that those actually developing the robot would be technical people, just wanting to create a cool robot.
>
> (Robotics engineer)
>
> When you are trying to solve this problem, you're not thinking about the ethics – you're just trying to figure [out] a solution to something technical. How do I get the robot to move this part from here, to here?
>
> (Robotics engineer)

If pressed, on where in the design it would even be possible to incorporate ethical decision-making, many of the engineers thought it belonged in the beginning, with the decision of whether to develop the robot or not – echoing the make-or-break thinking of existing engineering ethics frameworks (Lynch & Kline 2000). Indeed, some ethical problems, like job loss, *were* tied to the automation of the task itself.

> Some of these aspects, like reducing social interaction and maybe someone losing their

> job, are intrinsic to these projects that we do. So if we are *doing* a project, some of these questions have already been decided….[And for other types of projects], if you're not in on the design [planning] process, it's pretty much locked in.
>
> (Software engineer)

The engineers' formulaic approach to ethics mirrored their structured orientation toward design (see section 4.2). One reason, it seems, that the engineers had trouble locating ethics within their work processes, is that they held a very narrow view of ethics, built around automation and job loss (as evident in the industry discourse about saving jobs; see section 1.2). With this point of view, the choice to automate is *the* ethical issue. To reiterate what one software engineer pointed out: "…if we are doing a project, some of these [ethical] questions have already been decided." They also had trouble understanding the ethical implications of their work because they thought about ethics hypothetically, and could not envision negative outcomes aside from job loss (which they had already dismissed as an issue) and physical safety (which is already regulated). A possible explanation for this disconnect between their work and the greater impact of their designs could be a lack of training and experience in ethical thinking. The engineers reported that while they'd had coursework on regulations, safety, and legal issues, they had not had any education in ethics. In order to bring their ethical-thinking out of the hypothetical, I had to conduct another round of interviews using narratives from other engineers and from professional literature to provoke ethical reflection about their own work.

FINDING ETHICS IN DESIGN

The engineers had had trouble extending their views of ethics beyond discursive issues, like replacement and safety. However, when given real-life examples of ethical issues with implementation, the engineers finally understood ethics in a broader sense and were able to look beyond the ethical dilemma of whether to automate or not to automate. They told stories of industry workers whose work or livelihood was negatively affected by the engineers' own work.

> Back in the shipyard, I also heard something about that. I was not directly involved in this project, so I only heard about it. But it was a robot for welding pipes together. If you have one pipe connecting to another in a T, you have a very special welding seam, which the robot was made for. However, the trouble was that the workers were paid more for doing this complicated welding than for doing the end-welding when they have the flange. So, they indeed sabotaged the robot. Only because they were paid more for doing what the robot was doing! That was completely stupid, because if the company had done something about the payment, of course there would be no problem. Only because the loss of money that was seen from the workers' side.
>
> (Robotics engineer)

Another engineer shared a story about a process he'd helped to automate, in which a small data-entry task was automated in a process of bending sheet metal from CAD drawings to create parts. Three years after implementation, the workers were still not using the software, but were instead inputting the numbers manually.

> The people on the floor, they still wanted to use the old-fashioned way because that was what they knew, and actually they thought that they put value to the product. By doing things, they could use their skills to do it, even if it was just typing in some numbers that came from a drawing…. The leader said that he had seen that it was difficult to take off

> this responsibility because then they thought that their work was not as valuable. Even if they maybe could do some more metal sheets because they were not using time to enter the numbers. But it was difficult to get people to work like that. If you forced them to do it, they'd think their work was not that interesting anymore. Because putting the sheet metal in was not the interesting part. They thought it was nice when they had a new product: "Now we have to make this work," type in numbers, see that it actually forming some part, and say, "Yes! *We* did this." Instead of just starting the machine and putting in sheet metal.
>
> (Robot consultant)

Both engineers could see that their work negatively affected work processes and the lives of the workers, making their work less interesting, less valuable, or less profitable. Both engineers acknowledged that considering the effects on the workers beforehand might have prevented these outcomes. So although the engineers did not generally see a place for ethics within their practices, they were able to engage with a personal or professional ethical orientation toward design, when provoked. One young engineer, when asked whether he would feel ethical responsibility for a negative outcome resulting from his design, said that he wouldn't feel responsible, but that it would trouble him personally. He would like not to be involved in projects that might cause someone to lose their job, but he felt constrained by his position within the company.

> [The user's] unhappiness with the machine would hurt me- hurt my pride….I can't really decide which projects I pick, I'm mostly assigned. If I had the space, I would say no--- Actually, I haven't considered what would happen if I said no to a project—and I don't want to at all. They'd find some way to work around it. Maybe *I'm* not doing it, but now my colleague is doing it – is that so much better?
>
> (Robotics consultant)

Although the engineers typically expressed empathy for the workers, they did not feel responsible or liable for any ethical aspects or outcomes:

> Of course I would feel bad, but I wouldn't feel responsible.
>
> (System integrator)

ASSIGNING ETHICAL RESPONSIBILITY

Overall, the engineers did not feel that the consideration of ethics was a part of their existing practices, nor did they feel it was their responsibility to integrate it into their practices – despite having seen, and sympathized with, workers who were negatively affected by the engineers' designs. One reason for denying responsibility was attributed to a lack of agency in decision-making.

The robot consultant whose project involved sheet-metal bending said he felt frustrated with the company for not having gathered their workers' opinions on which tasks to automate. However, he did not feel that was his decision to make and felt constrained by the agential hierarchy of commercial projects: "It is the customer who takes the last decision. The man with the money decides." Other engineers felt that their ethical decision-making agency was constrained by structural elements like workplace hierarchy, as in the example above, or by budgets. As several engineers explained, everything they do in the design process has to add economic value. In the end, 'productivity' rules – the point of the robotic solution is to make the total human-machine production process more efficient and cheaper.

> That's the logic in industry. Does it make money? No, it doesn't. Then we can't.
>
> (Software engineer)

> Sometimes they [operators] are annoyed with the robot, because it doesn't do it the way that they would have liked it to be done. And now they even have to provide it with resources the way that it says it wants it. So, that can sometimes give some negative reactions…"Why do we need the robot if it's slower than us?" Well, because it doesn't have lunch. Or it doesn't go for lunch breaks. It works at night as well. It doesn't complain. It just does what it's told.
>
> (System integrator)

When asked who *did* have a responsibility to ensure an ethical product or ethical outcomes, the engineers deferred responsibility. The software developers pointed to the system integrators who pointed to the client (i.e., the factory manager) who pointed to the government.

> We don't think about the social perspective of the operator. But that is also because we have these specifications that this machine has to perform against. And if that is causing a bad day for the operator, that responsibility lies not with us, but with the person who specifies and buys the machine – the customer.
>
> (Software engineer)

> It's the customer's problem, whether the worker is happy or isn't happy.
>
> (Robot consultant)

> I don't know, you can say that the government is setting the direction, saying that we should install more robots. And they know about the societal ethics, effects that it will have. So they are somehow responsible.
>
> (System integrator)

Thus, the HECHO engineers may have had an ethical orientation toward design and toward users, but felt no responsibility for the harm their designs might cause. They thought ethics were important, and came to realize that ethics was relevant to their projects, but still did not think it part of their practice to consider ethics. This is symptomatic of their theoretical orientation toward ethics, and their practical abstinence. The engineers' decision-making agency, limited by the social arrangement of the project, affected the engineers' assignment of ethical responsibility. They not only felt that they weren't responsible for considering ethics, they also felt it wasn't possible.

On the contrary, ethics *can* be brought into the design, in the form of values. As shown with the *flexibility* example (section 4.2), values *can* be a part of technical problem-solving – not only in the planning stages, but throughout the design process. While flexibility was a functional value, I argue that we might incorporate the underlying human values (the human value *inclusion*, for example, underlies the functional value *accessibility*).

Whereas the engineers' technical decision-making had been marked by social negotiations, this was not the case with ethical decision-making. The ethical principles they held, however loosely, never translated to actionable values and did not come through in their work. But, by having these conversations with the engineers, their understandings of ethics expanded and they were able to connect the ethical effects of their products to their own design processes. In this way, there was some learning occurring between the engineers and myself, signaling that ethnography itself might play a role in the design process- in defining the new realities produced when engineers and ethnographers work together (see section 7.2). Perhaps, ethnographers can provoke engineers to consider *human* values alongside functional values as a part of their everyday design practices.

6.3 Conclusion

In a review of engineering ethics, including an examination of professional engineering association membership documents, I have found that existing formalized attempts at engineering ethics have been virtue-based and individual-oriented. The canons and principles contained in the codes of conduct that professional engineering associations promote are not actionable. These formalized ethics approaches push an ethical orientation or a way of being, rather than a way of acting. Not surprisingly, such oaths and edicts have been ineffective and clash with the very social and pragmatic nature of design decision-making.

The HECHO engineers had very little experience engaging with ethics. They had had no training or schooling in ethics and had difficulty understanding how it might fit into their work. Like with their conceptions of design, their ideas about ethics were theoretical rather than practical, and were in line with formal approaches to engineering ethics. They mostly discussed ethics with regard to job loss and physical safety. Therefore, they held the opinion that ethical considerations ought to be made in the earliest stages of design (if included in the design process at all), and did not ascribe any ethical responsibility to themselves. Like with the design plans which were inconsistent with design practices (chapter 4), there was a disconnect between systematic virtue ethics (plans) and the pragmatic work of engineering design. Ethics were simply not a part of the HECHO engineers' everyday practices. Values, however, were. Therefore, I promote a move from theoretical ethics to practicable values.

7. DISCUSSION

While formalized ethics have failed to enter the HECHO engineers' design process, the engineers were nonetheless practiced in engaging with particular *economic* and *functional* values, which might be underlain by *human* values. If engineering ethics can be translated into *human* values, then it can be enacted in the sociomaterial practices of design. Therefore I argue that instead of proposing more codes of conduct (e.g., European Parliament 2017) that target ethical *engineers,* perhaps the focus should pivot to ethical *engineering*, bringing ethics ought to the practice level alongside everyday design decisions as *human values,* rather than as moral principles.

One way to make this shift, I posit, is through ethnographic research. Through an assessment of the social arrangements of decision-making, and through ethnographic inquiry, it might be possible to bring diverse groups into dialogue, to blend disciplinary understandings, and to spark ethical reflection and the integration of values into everyday design activities – thus bringing about more ethical realities.

7.1 A NEGOTIATION OF VALUES

As shown in chapters 4 and 5, design is pragmatic and social: it involves a process of decision-making that goes between conception and action, and processes of social negotiation mediated by design artefacts. A social and pragmatic design process deserves a social and pragmatic ethics. For the HECHO engineers, it was difficult to engage with ethics on a practical level. This may have something to do with how ethics has been approached within the engineering profession. Devon Van de Poel, advocates for a social ethics of engineering argue:

> "Despite the considerable recent growth in the literature and teaching of engineering ethics, it is constrained unnecessarily by focusing primarily on individual ethics using virtue, deontological, and consequentialist ethical theories. (Devon and Van de Poel 2004, 461).

Current engineering ethics approaches focus on ethical orientations, *theoria*, rather than value-driven practices, *praxis* (Schmidt 2014). Engineering ethics presupposes that an orientation will effect a consideration for human needs in design. This has not been the case in this empirical study. A value-oriented engineering, however, would flip the situation, bringing human values into practice and *thus* transforming the ethical orientation. Rather than focusing on ethical *engineers*, the focus would be on ethical *engineering*. Therefore, I propose a shift from engineering ethics to engineering values.

Why 'values'? First, values are already a part of design discourses. Friedman and Kahn (2006) have already created a value-sensitive design framework. I am not the first to suggest a pivot to a pragmatic ethics in engineering either: Mike Martin and Roland Schinzinger (1996) as well as William Lynch and Ronald Kline (2000) have suggested a move from consequential ethics and edicts to a more pragmatic ethics. I simply suggest that values and engineering are both pragmatic, and that engineers engage with functional values already – such as flexibility, agility, efficiency. The significant shift will be in expanding the types of values incorporated into their design processes. Here, I suggest that ethnographers might play a role (see section 7.2) in provoking such a shift.

Value comes from the Latin verb *valere* ('to be able', 'to be worth') (Hoad 2003), denoting an ability and a quality. *Ethics*, by contrast, assumes a field of knowledge, a set of values, and perhaps a philosophical orientation toward those values (WFEO 2001). Ethics and morality derive from the respective Greek and

Latin terms *ethos* and *moralis* ('character', 'manner', or 'conduct'), denoting a way of being. A particular engineer might identify with an ethics or a moral orientation that does not necessarily effectuate the consideration of values in design practices (as shown in section 6.2). Ethics are rather theoretical until operationalized into values.

Values, by contrast, are practicable. They can be tangible and specific, such as *flexibility* in modular robotics design, which describes the ability to adapt the robotic cell. Whereas ethics typically concerns just one type of value (human values, or moral rights and wrongs), there exists a plurality of value types (functional, economic, e.g.) which are *socially* and contextually determined (Graeber 2001; Kluckhohn 1951; Doyle 2009). The engineers have experience incorporating these other value types into their work, and negotiating their worth. In the HECHO project, *flexibility* was negotiated throughout the design process. From its introduction into the project via the work-package, with the goal to develop "flexible automation," to the selection of particular design features or components. Here, the value that the engineers engaged with in practice was not a human value, relating to ethics, but was functional value. The meaning and worth of *flexibility* was negotiated by the engineers, buyers, and funding organizations involved in the cell's development and implementation.

Ethics, in contrast, tend to be *individually* internalized principles (Safire 1984). Thus, engineering values are more pragmatic *and* more socially oriented than engineering ethics. Building on Steen's (2015) explanation of pragmatist ethics, value-oriented design activities can be a practice, a primary experience, whereas ethics is theoretical, a reflection or a secondary experience. Even when the HECHO engineers possessed moral attitudes or subscribed to codes of ethics - ethics remained inert unless enacted. When they relegated their ethics to the conceptual stage, or deferred ethical considerations to other parties, they effectively cut these ends (ethical outcomes) off from the means (the value-oriented design process). Their ethics were simply not integrated into their everyday activities. This is an essential point, because it is the minute everyday decisions – the social negotiations – that make up the design process; and it is therein that ethics can be translated into values.

Therefore, I suggest that ethics ought to be brought forth through the everyday social negotiation of (human) values. And, because engineering design is a shared activity between people, it makes sense that an engineering ethics would be an activity between people – a social ethics. There may also be intrinsic value in a value-oriented engineering design, in which the collaborators, as they incorporate values into the material and social practices of design, can come closer together in their ethics, their orientation toward design. Just as they negotiated other boundaries of culture, discipline, and knowledge, they might negotiate their separate ethos. Their object-world negotiations, I argue, ought to include human values, in order to create new – more ethical – realities through design.

7.2 Ethnography as provocation

I have suggested a shift from engineering ethics, to a more pragmatic and value-oriented engineering. Here, as a point of discussion, I suggest that ethnographers can play a role in bringing particular human values into design – by bridging object-worlds (between engineer and operator), by provoking ethical reflection to identify relevant human values, and by identifying opportunities for value-oriented technical decisions. I propose that by expanding the values that engineers incorporate into their everyday design practices, we might create new realities that may lead to more ethical orientations in engineering. One way that we might realize this shift is through ethnographic research in robotics development.

What is the active role of the ethnographer, as a social scientist, beyond describing the engineers, their object-worlds, and their social practices? In conducting ethnographic research, I entered the design process with my own object-world about me. I came with different experiences and understandings of technologies as artefacts, as cultural products, etc. My object-world was changed significantly (see section 5.1) as I became familiar with the jargon, the parts, and the practices involved in the HECHO project. However, I too, brought with me some expertise and experiences which might have changed the participants' understandings. I asked questions about ethics, morals, and consequences. I drew attention to operators' experiences, societal needs, and caused the participants to reflect on their own practices. A disruption of their relatively structured approach to design might open the process up to new ways of understanding the operators and the robotic cells themselves:

> The contribution that ethnography may make is to enable designers to question the taken-for-granted assumptions embedded in the conventional problem-solution design framework. (Anderson 1994, in Buur & Sitorus 2007, 146)

Just by examining the HECHO sociomaterial assemblages through the lens of social ethics, by raising issues of values and ethics with the engineers, I noticed an increase in their attention to ethics, their ability to locate clashes of values or interests in design, and in their orientation toward the design process. Perhaps, further involvement might instigate a similar increase in attention to human values in their everyday design practices.

Therefore, ethnography might be seen a form of world-making or knowledge production (Rapport & Overing 2002). John Law and John Urry (2004) suggest that social scientists create certain realities when they select particular methods, perspectives, and inquiries. Citing Donna Haraway, they call social science a *system of interference* (Law & Urry 2004, 397), and argue that if our investigations build new realities, we [social scientists] can make political choices about what type of realities we want to contribute to. As Lucy Suchman writes, "The representations ethnographers create, accordingly, are as much a reflection of their own cultural positioning as they are descriptions of the positioning of others," (1995, 62). By choosing to pay attention to ethics, and to draw attention to human values, and by writing this thesis thusly, I have already instigated a new reality.

Ethnography has been used in the past as design provocation. Jacob Buur and Larisa Sitorus (2007) have used ethnographic materials to "provoke engineers to reframe their perception of new designs." In a participatory-design project at Ingram (coincidentally), Buur & Sitorus brought operators into the design process to engage in direct dialogue. This helped the engineers to better understand how the operators worked – and how the engineers' new technologies might shape or support their work. They also used ethnographic material (videos) to prompt engineers to discuss how they understand the design product itself.

> The [ethnographic] material mediates the exchanges of understanding and perspectives of various practitioners. [Eleanor] Wynn argues that by creating openings within the boundaries that form such practices, one diminishes the distance between these practices (Wynn 1991). These openings take place when designers are willing to be more sensitive towards the boundaries (Wynn 1991). Ethnographic material can help these practitioners expose, exchange and reframe their understandings. (Buur and Sitorus 2007, 155)

As shown in chapter 5, engineering involves a social negotiation across object-worlds. If an ethnographer were to provide ethnographic material that provoked a dialogue about ethics and human values, perhaps it would open a space where the engineers could negotiate values as part of their everyday design practices. Indeed, EunJeong Cheon and Norman Makoto Su (2018) are currently attempting to elicit values in design processes, through the use of futuristic autobiographies developed from empirical narratives. While this study is a step in the right direction, it focuses on invoking values within an individual – not within the social context of design. From a sociomaterial perspective, agency (and by extension, moral agency) does not exist a priori, but is negotiated within a situated practice (Nickelsen 2015; Suchman 1987). Therefore, such a practice of ethnography as provocation or as interference, should be done with a social ethics approach – taking into account the entire assemblage.

So, if there is to be a pragmatic move from ethical engineers to ethical engineering, perhaps it can come through ethnographic provocation and social ethics. By examining the social arrangements and decision-making processes involved in a particular design, and by provoking engagement with human values in the design process, by crossing object-worlds and working interdisciplinarily, ethnographers might play a role in a more critical design process.

8. CONCLUSION

My aim in conducting fieldwork around robotics engineers was to learn more about who made robots, how they negotiated decisions in their design processes, and to explore whether there might be room in these negotiations for ethical reflection. Inspired by the EU Parliamentary resolution that identified a rising societal need for more ethical robotics, and proposed new regulations on robot creators, I embarked on a 5-month fieldwork in the robotics hub of Denmark. By studying the social arrangements of decision-making among the HECHO engineers, I have come to understand design as a problem-solving process of sociomaterial negotiation, and have thus suggested a move away from individual virtue ethics toward a social and pragmatic ethics based around human values.

From a social ethics methodological perspective, I examined the sociomaterial assemblages of the HECHO engineers, within which everyday design decisions were made. I observed the engineers' primary activity, a process of problem-solving, through which they negotiated design plans and ideas and contested them through sociomaterial design practices. Their plans were influenced by formal design process models and organizational project management approaches. However, these rather explicit plans were transformed into actions in everyday design practices, which involved more implicit decisions influenced by the social negotiation of understandings and interests, and of hierarchy and values. These design processes were a pragmatic back-and-forth between conception and action.

This pragmatism was mirrored in the interdisciplinary interactions among the HECHO project members. When the engineers' collaborated and their object-worlds collided, they negotiated language, disciplinary knowledge, roles, and materials. Through their use of design artefacts, the engineers made decisions from their own understandings shaped by their individual object-worlds. The interplay between the engineers' own object-worlds and their collective design activities was pragmatic in that the existing theories, interests, and understandings an engineer held affected the way they undertook their work. In turn, new work experiences and materially-mediated interactions informed and altered these understandings and orientations – essentially a form of world-making. By learning to navigate these boundaries of culture and experience, they shaped new artefacts and new realities together. As an ethnographer, I also contributed to this world-making, which led to the question: If we are co-creating new worlds, how can we purposefully build realities that reflect our shared values?

The pragmatism that defined the social negotiations in the design process did not carry over to the engineers' ethics. Unlike their theoretical orientation to design, which was translated into explicit decision-making and contested through implicit decision-making, the engineers' theoretical ethics were not drawn into their everyday design practices at all. Ethics was relegated to a theoretical corner of the design process, was deferred to other parties, was dismissed as not applicable, or was simply missing. In a review of engineering ethics, I've found that these prescriptive virtue-based approaches are doing little to bring ethics into actual engineering practices. They come in the form of oaths and codes of conduct – like the recent EU resolution proposed – whose canons are not actionable. Values, on the other hand, can be negotiated and enacted through material design practices.

Thus, I've suggested a move from engineering *ethics* to engineering *values.* The shift from ethics to values, entails a pragmatic shift from theory to practice, or from orientation to behavior. With this shift comes a parallel move from the individual toward the social, from the virtuous engineer to ethical engineering, a social practice among engineers. Such a move, toward a social and pragmatic ethics, would involve looking at the structures and social dynamics of decision-making behavior that ultimately have an ethical/moral effect in the world – as I have done in this fieldwork – and identifying opportunities for value-oriented decision-making.

Through ethnographic inquiry, as provocation or interference, the HECHO engineers were able to engage in ethical reflection – together we were able to reframe ethics by way of *human values* particular to their own projects*;* values being something the engineers were familiar with (e.g., economic value, functional values). My humble proposition is that ethnography can continue to play a part in design by initiating a dialogue around human values.

◊ ◊ ◊

I have argued that a sociomaterial and pragmatic engineering calls for a social and pragmatic ethics, that such an ethics would rely on a shift toward human values, and that such a shift might occur through social ethics and ethnography as a provocation. By examining the social arrangement of design and decision-making processes, by prompting engineers to reflect on ethical issues in past projects, and by spurring their engagement with relevant human values identified through ethnographic enquiry, ethnographers might contribute to a more ethical world-making.

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APPENDIX

The following selection of interview guides and other methodological tools, engineering documents, and photos provides a sample of the material used throughout the fieldwork.

INTERVIEW GUIDES

Planning / Design

1. Can you tell me about how you became involved in the HECHO project?
2. How do you usually take on new projects? From calls? Internal proposals?
    a. Who funds these?
    b. What types of projects are they? Research? Commercial?
3. Which projects allow for the most room for innovation / creative expression?
    a. Are they application specific? Flexible robot solutions?
    b. When do you feel you are most in charge of your work?
    c. Do any of these projects go to market? Are they intended to? Or are they particular solutions for a client?
4. What is the purpose of the HECHO project?
    a. Who set this goal/aim? Do you agree?
    b. Did you have other, personal/professional goals in this project?
5. What was your individual motivation going into the HECHO project? What did you hope to achieve?
    a. Did you achieve it? Why? Why not?

Development

6. What role did you play in the planning of the HECHO project?
    a. Were your particular goals or ideas incorporated into the project design?
    b. How closely does the final system resemble the initial plan?
7. Can you describe your contribution/component?
    a. Do you recognize your own work in the robotic system now?
    b. Is it as you intended?
    c. What kind of compromises have been made?
    d. Is there anything you wish you could change?
    e. Were your personal goals realized? Why/why not?
8. Did you collaborate personally with anyone?
    a. How would you describe these collaborations?
9. Were there any moments of disagreement? About the goals? About the ways to achieve them? About the design?
    a. Can you describe these processes of negotiation?
10. If you wanted to change something about the design, how would you go about it?
    a. Who has the authority to initiate a change?
    b. What about your particular contribution? How much freedom do you have in shaping your work?
    c. Who determines *what* must be done and *how* to achieve it?

Ethical responsibility

11. Who is responsible for any positive or negative effects in the workplace as a result of implementation of this robotic system?
    a. If someone is relieved of a repetitive task? If production costs are lowered and the employer is able to retain more workers in Denmark? OR, if a worker's hours are reduced?
12. Do you feel responsible for any outcomes at all? OR, what *do you* feel is your ethical responsibility?
    a. Why?
13. Do you think about the outcomes/effects of implementation when you take part in a project?
    a. At what point? Conception? Design? Development? Implementation?
14. If you did foresee an ethical issue, is there anything you could do in your work, personally, to minimize negative effects?
    a. Or, is this something someone else should/could/would handle? Why?

5-question interview

1. Thinking back on a recent collaborative (robotics) project, can you describe a situation in which you contributed or proposed a new idea or innovation that was: *Accepted*? *Rejected? Negotiated*?
    a. Can you describe a particular project or project type in which you generally have the most room for innovation / creative expression? (e.g. Applied research versus open research? Application specific? Flexible robot solutions? Funded? Commercial? Collaborative?)
    b. When do you feel you are most in charge of your work?
2. Did the final product reflect your particular contributions, ideas, innovations, work?
    a. Do you feel your ideas were heard? Why or why not?
3. Were there any positive or negative effects as a result of implementation of this particular robotic solution?
    a. If there were any real (or hypothetical) effects, who would be responsible for these effects? [For example: If a particular robotic solution results in fewer peer-to-peer interactions? Or a decrease in mundane or repetitive tasks?]
    b. Do you feel responsible for any outcomes at all? OR, what *do* you feel is your ethical responsibility? Why?
4. Did you think about the outcomes/effects of implementation when you took part in this project? In other projects, in general?
    a. At what point? Conception? Design? Development? Implementation?
5. If you did foresee an ethical issue, is there anything you could have done in your work personally to improve the machine or minimize negative effects?
    a. Why? Why not?

Start-Up hub questions

1. Could you describe how the start-up hub was established? Whose idea? What was the inspiration?
2. Who funds the development processes?
3. What is the purpose of the hub? How does it function? Who takes part? (e.g. students, recent graduates, working professionals) How do they become involved?
4. What kind of projects are brought to the hub? What kind of new projects have emerged?
5. Have any new collaborations emerged as a result of the hub?
6. What does GTS stand to gain for hosting?
7. What kind of support or interaction with local (GTS) researchers, engineers, do the start-ups have? Why do these individuals get involved?
8. How do the terms 'collaboration', 'innovation', 'co-location' relate to the activities in the start-up hub?
9. Can you give five words of your own to describe the start-up hub?

Observation follow-up

Why are there two cells?

You had a discussion with (Emil)/Gustav about adapting some sort of sprayer?, with a basin, into a module. (It stood on the counter and you suggested the parts could move along a rail, like a 3D printer.) Have you discussed this further with (Emil)/Gustav? Could you elaborate more on this discussion? Have any decisions been made?

> (Gustav) It's an air-knife.
>
> (Emil) I can provide input in terms of the design, sparring partner, you could say, but I don't want to decide – it's completely up to them how to do that. They are the experts in the process. I give some input to the solution, but they basically decide how they want to do it.

You also discussed the mounting hardware, but I was unable to hear that conversation. Were you troubleshooting? Considering other parts? What was the conclusion?

> Emil wants to create general parts to build other modules from.

(Emil) Then, you briefly discussed the weight of one of the modules. It seems that Gustav would like them to weigh 10kg or less. Could you tell me more about this?

(Gustav) You have said that the modules must weigh 10kg or less, Emil seems less firm on this – can you speak to that?

> (Emil) It needs to weigh whatever it weighs.
>
> (Gustav) For me, it's not a big priority. For ManuTech, it's an indirect priority because it's a priority with the end users.

What was the discussion you and Emil/Gustav had about the cables (power, connectivity)? And about the light panels, switching to industrial LEDs? What is the purpose of these? Any resolutions?

Communicating safety state of cell. Red, yellow, green, blue, etc. Safety, communicating proximity of human.

I noticed that there was trouble with the software and with getting the new module running. Could you talk a bit about this?

At some point, Emil/you asked about a particular term in the control software and you/Gustav replied "Det er ROS-specific, så bare lad den være." There was confusion in the lunchroom, as well, about certain terms/language (fx "driver"). Later, Alexander clarified terms like "skills". Can you tell me more about how jargon/work-language comes into play in a collaboration like this?

It is my impression that although the cell is built, and the plans have been laid, there are still micro-decisions being made and new ideas cropping up.

What is your motivation in having Jens learn to program the modules himself? Whose idea was this? What is the typical education level of the ManuTech workers who would be programming these modules? What kind of training/knowledge/tools/education do you think is necessary for GTS to step back and ManuTech to program and sell the STACK cells/modules without GTS specialists' help?

(Fx- You had suggested a PDF or video tutorial/guide. Has there been a decision on this?)

Do you anticipate users programming new skills for their systems? Or would they call you? GTS?

It seems, from my first impression, that safety has been considered (whether by obligation or design choice, or both) in many ways for this cell. Because the STACK cell is being developed as a standard modular product (without a particular application, user, end user in mind), it may be difficult to consider ethical, societal issues.

Ask Gustav: How might one consider ethical/societal issues if the cell has no end user?

Timeline interview & robot mapping guide

The purpose of my interview with my primary informant on Thursday 31 August is to:

- Get an overview of the project
- Understand the material components of the robot
- Identify potential informants from the HECHO project and other projects

This will be achieved by using two methods of interview:

- Timeline interview (the robot's or project's "life history")
- Robot map (the robot's "anatomy")

From these two methods, I hope to generate a project network, which shows who was involved in the project or the robot's creation, and what their roles were. This will be useful in beginning to understand the robot as a distributed technology, to understand how collaborations have taken place, and to identify informants for future interviews.

To participants:

"Let's start by drawing a timeline of the project from conception to today. Then, can we draw a map of the robot itself, it's hardware and software components. From these tools, can we elicit a project network, to see who is involved, when, and in which way."

Timeline interview

To participants:

"I'd like to start by having you draw a timeline of the project. While you draw, I will take notes and ask questions so that I can get a more thorough understanding of the project. Please include any events you consider significant, from the project's (pre)conception through to the project's future."

Interview guide

The following semi-structured interview guide includes questions related to this particular interview scenario. The questions are numbered for ease of use, but no particular order or hierarchy is intended.

1. Whose idea was this?
2. Who worked on this?
    a. Who else contributed?
3. When did they become involved?
4. Who funds this?
5. Who is the coordinator / lead?
6. What is the purpose of the robot/project?
    a. Who set this goal/aim?
    b. Do you agree?
    c. Do you have other, personal, professional goals in this project?
7. Who decided how this would work?
8. Why was this important?
9. Were there alternatives?
    a. Why this one?
10. How did pre-set goals / deadlines impact these events?
11. Did you meet your goals / deadlines?
12. Were any compromises made in order to fulfill project goals / deadlines?
13. What kind of challenges did you face?
14. How were these overcome?

About network (maybe move to Project Network section)

1. Who is involved? Integrators, end users, partners, investors, universities?
2. Who is involved from your organization? Mechatronics, software, HRI, admin?

Other interview questions

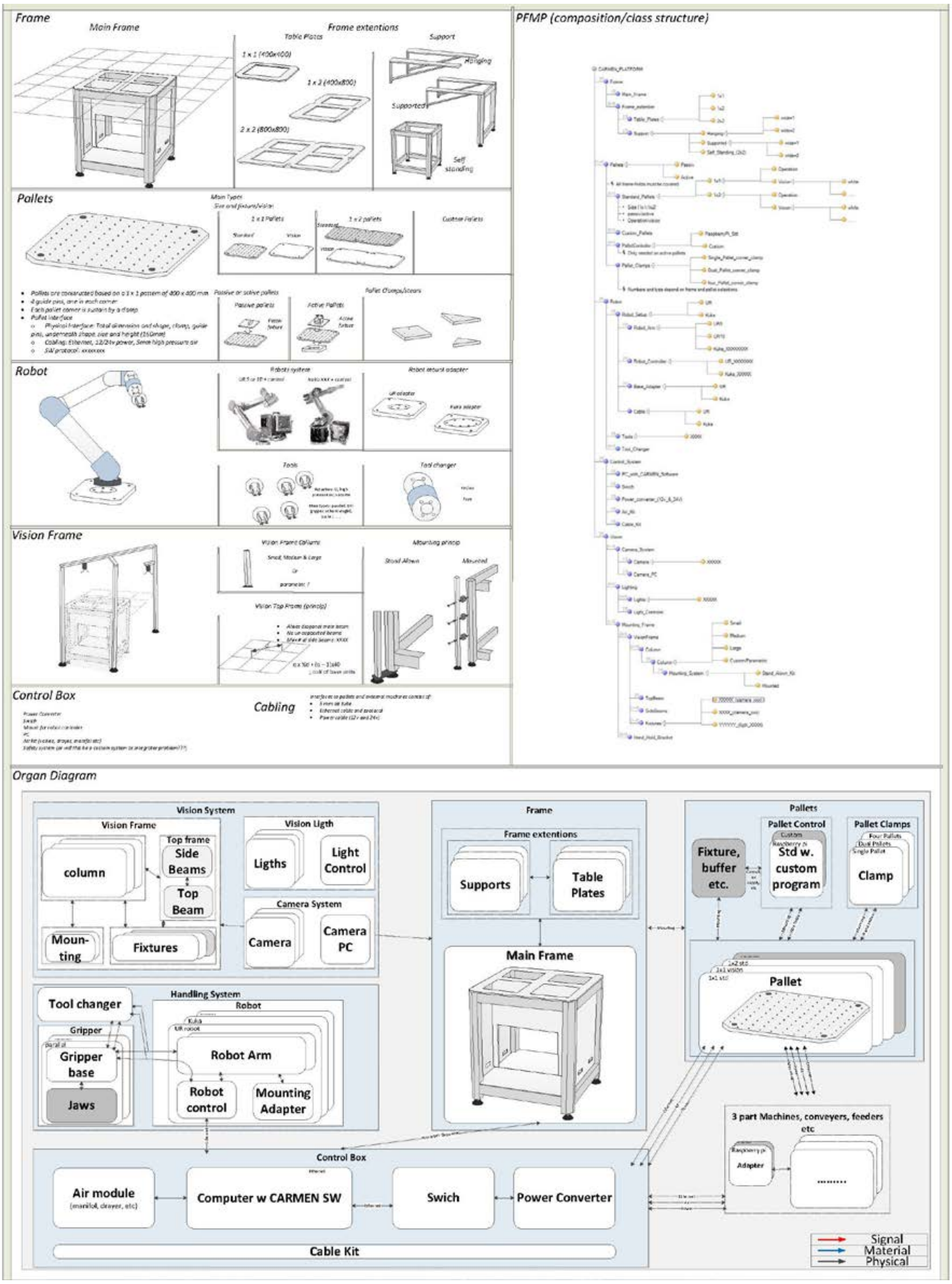
1. Can you explain how your organization takes on new projects? From calls? From internal staff? Universities? Whose ideas? Market analyses?

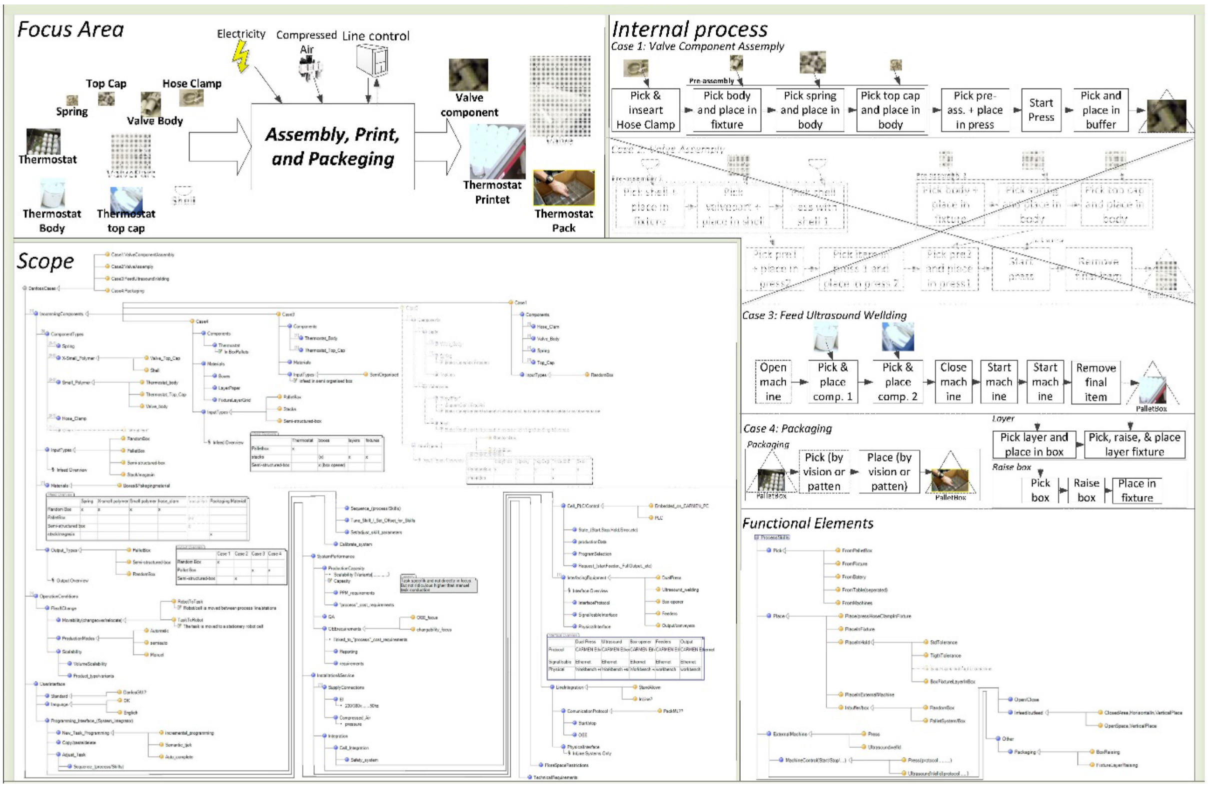
2. How do you decide which projects to begin?
3. How are projects funded?
4. Do (externally) funded projects allow for adequate space to innovate / explore?
5. Which projects allow for the most room for innovation / creative expression?
6. Are they application specific? Flexible robot solutions?
7. How many of your projects would you say are “internal”`? How many are for clients or responses to calls?
8. How much of your work is R&D versus product development?
9. Do any of your projects go to market?

Next steps

I plan to present the timeline created during this interview to other informants, giving them the opportunity to modify or add to the existing timeline. From this exercise, I hope to co-construct a memory of this project, to identify certain power relations between participants, and to understand their various motivations and interests in the project.

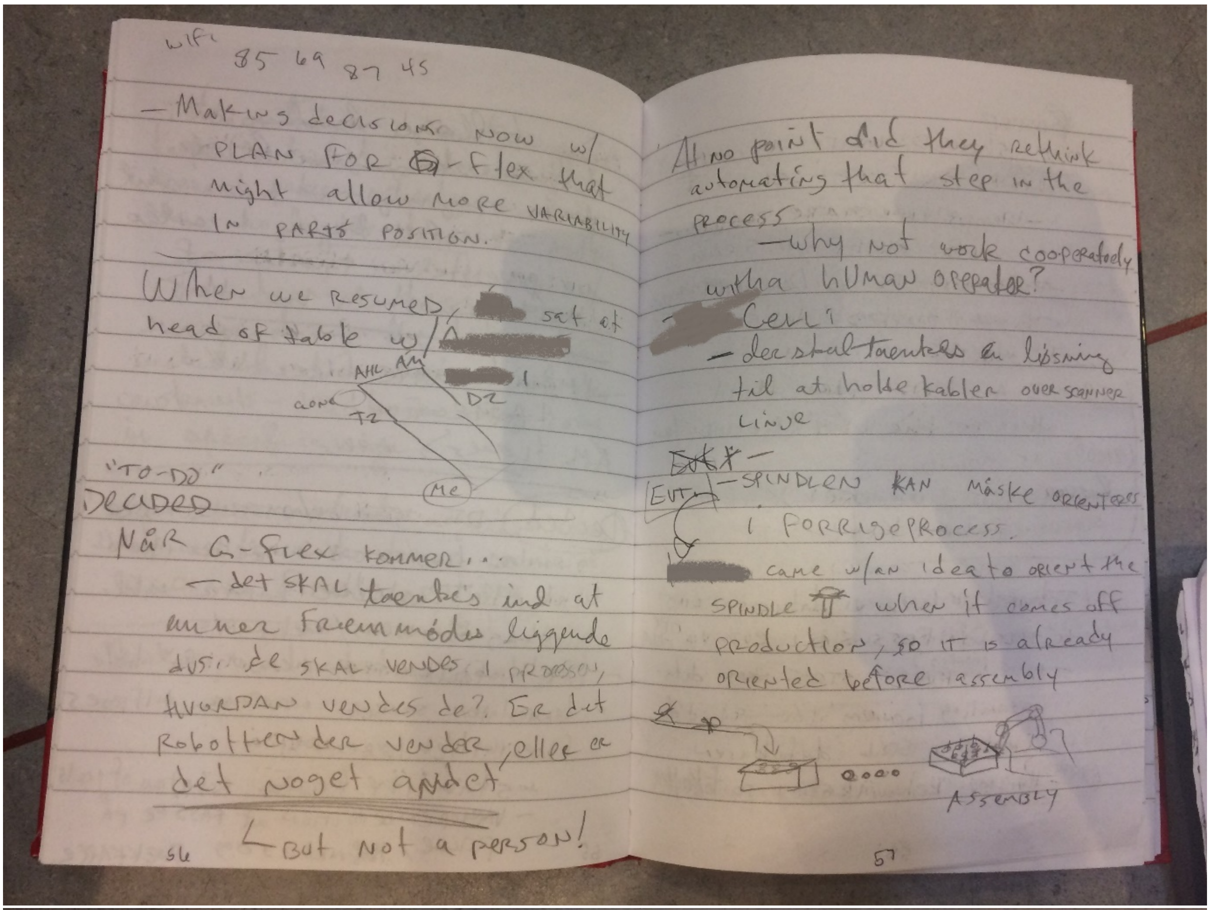
ENGINEERING DOCUMENTS





Focus Area
Electricity
Compressed Air
Line control
Top Cap
Hose Clamp
Spring
Valve Body
Thermostat
Assembly, Print, and Packeging
Valve component
Thermostat Body
Thermostat top cap
Thermostat Printet
Thermostat Pack
Internal process
Case 1: Valve Component Assembly
Pre-assembly
Pick & inseart Hose Clamp
Pick body and place in fixture
Pick spring and place in body
Pick top cap and place in body
Pick pre-ass. + place in press
Start Press
Pick and place in buffer
Case 3: Feed Ultrasound Wellding
Open mach ine
Pick & place comp. 1
Pick & place comp. 2
Close mach ine
Start mach ine
Start mach ine
Remove final item
Case 4: Packaging
Packaging
Pick (by vision or patten
Place (by vision or patten)
Layer
Pick layer and place in box
Pick, raise, & place layer fixture
Raise box
Pick box
Raise box
Place in fixture
Scope
Functional Elements

Fieldnotes



wifi 85 69 87 45

— Making decisions now w/ PLAN FOR G-Flex that might allow more variability in parts position.

When we resumed, [redacted] sat at head of table w/ [redacted]

AHL [redacted]

DZ

TZ

"TO-DO"

Decided

Når G-Flex kommer..

— det SKAL tænkes ind at emner fremmødes liggende dvs. de skal vendes i processen, hvordan vendes de?. Er det robotten der vender, eller er det noget andet

└ But not a person!

56

At no point did they rethink automating that step in the process

— why not work cooperatively with a human operator?

[redacted] Cell?

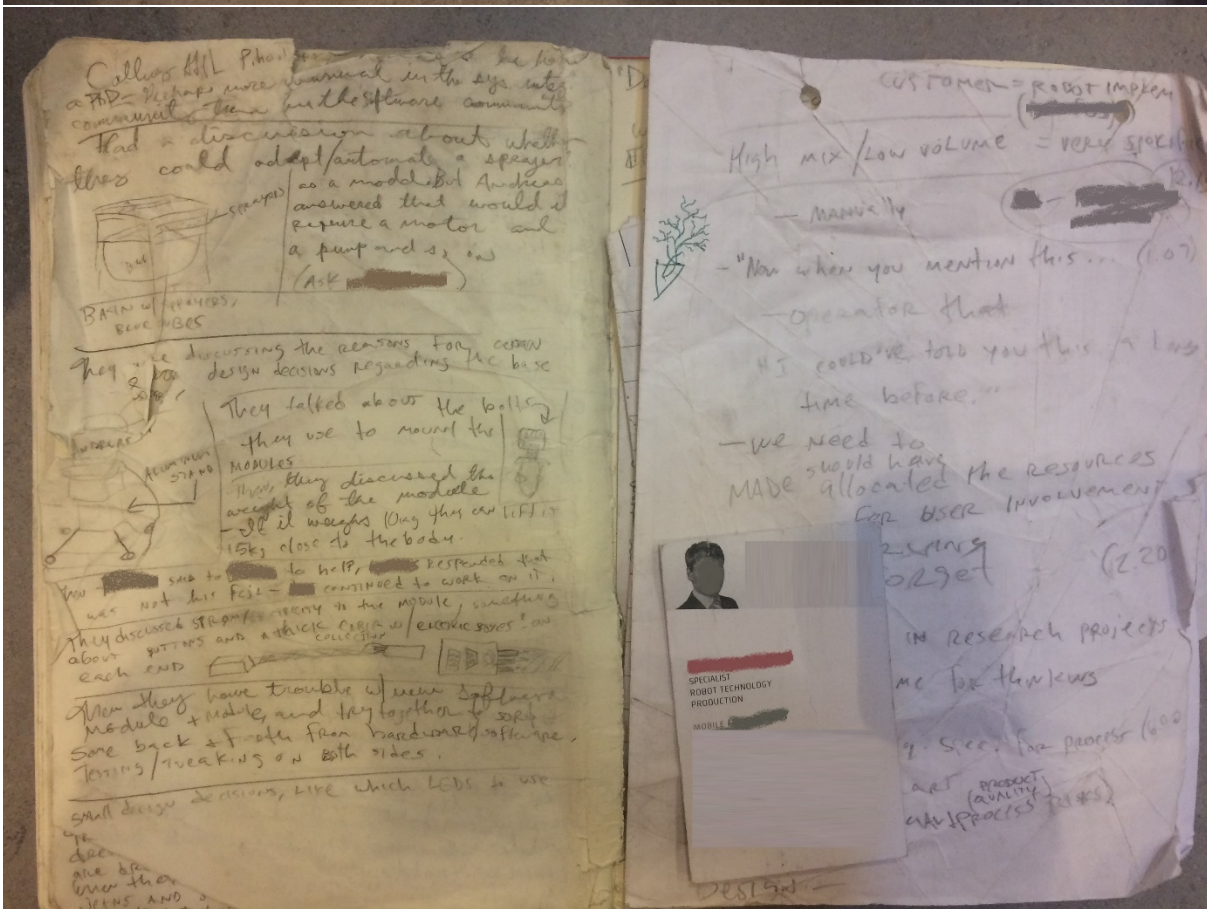
— der skal tænkes en løsning til at holde kabler over scanner linje

— SPINDLEN KAN måske orienteres i forrige process.

[redacted] came w/ an idea to orient the spindle when it comes off production, so it is already oriented before assembly

ASSEMBLY

57



Calling AHL Ph.D. ... a PhD — Perhaps more communal in the sys. integ. community than in the software community

Had a discussion about whether they could adopt/automate a sprayer as a module. But Andreas answered that would require a motor and a pump and so on

(Ask [redacted])

SPRAYERS

BASIN w/ SPRAYERS, BLUE TUBES

They were discussing the reasons for certain design decisions regarding the base

They talked about the bolts they use to mount the modules

Then, they discussed the weight of the module — If it weighs 10kg they can lift it 15kg close to the body.

ALUMINUM STAND

[redacted] said to [redacted] to help, [redacted] responded that was not his fejl — [redacted] continued to work on it.

They discussed strong electricity to the module, something about buttons and a thick cable w/ electric boxes on each end

COLLECTION

When they have trouble w/ new software module + module, and try together to sort ... back & forth from hardware/software. Testing/tweaking on both sides.

Small design decisions, like which LEDs to use

CUSTOMER = ROBOT IMPLEM.

([redacted])

High mix / Low volume = very specific

[redacted]

— manually

— "Now when you mention this... (1.07)

— operator that

"I could've told you this a long time before."

— we need to should have MADE allocated the resources for user involvement

forget

(2.20)

in research projects

me for thinkers

Spec. for process (6.00

PRODUCT QUALITY

and process risks

SPECIALIST
ROBOT TECHNOLOGY
PRODUCTION
MOBILE [redacted]