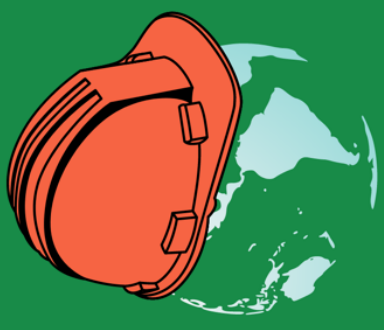
SUSTAINABILITY IN A RIGID CHAOS

Design suggestion for successful planning tool implementation on the construction site.



Aalborg University Copenhagen

Department of Sustainability and Planning

Master in Sustainable Design – 4th Semester

Project Title: Sustainability in a Rigid Chaos

- *Design suggestion for successful planning tool implementation on the construction site.*

Duration: 01.02.2024 – 07.06.2024

The total number of pages: 62 pages

The total number of normal pages: 50 pages

The total number of characters with spaces: 120.000 characters

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1. ABSTRACT

This thesis explores how sustainability can be enhanced in construction site planning. Using Actor-Network Theory (ANT) and methods like desk research, expert interviews, and observations, the study identifies obstacles for effective site planning such as rigidity and divergence between theoretical planning and on-site activities. These insights inform practical design solutions for planning devices using a morphological chart method. The resulting design aim to minimize holistic waste and improve sustainability on construction sites, providing actionable recommendations.

KEYWORDS

Holistic waste, Sustainability construction site planning, Danish construction sector, Theoretical and practical dissonance, Lean Construction

ACKNOWLEDGEMENT

Throughout this master thesis we have had the pleasure of working together with many very competent actors in the sector of construction site planning. We have been so fortunate to have had access to empirical sources that were very open and always ready to help in any way possible.

We would like to thank Morten Jensen for opening the network of Lean Construction-DK, Ole Berard for insights on digitization in construction and ConTech Lab for providing a venue and resources that support this thesis.

Also, thanks to Morten Pilebo, Wicki Trine Søgaard and Egon Lisberg form MT Højgaard for making a field study possible at a construction site. Also, a thanks to ABC Rådgivende Ingeniører for the access to a construction site in Northen Zealand. Furthermore, thanks to Søren Wandahl, Christian Koch, Martin Veis, Rasmus Berthelsen for their knowledge sharing in this topic.

A special and very grateful thanks to our supervisors, Andres and Jens, for the exchange of knowledge and very dedicated collaboration for making this thesis. Your deep knowledge in theory and sustainability has been profoundly valuable throughout the whole creation of this thesis.

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2. INTRODUCTION

Construction sites generate a significant amount of new material waste, estimated to be around 10% (Indenrigs- og Boligministeriet, 2021). Inefficiencies like these often stem from numerous mistakes and poorly conceived decisions, which contribute to creating stressful and frustrating environments (Arkitektforeningen, 2023; Appendix 3). Despite digital possible solutions for meticulous planning, construction sites often appear to lack proper organization and order. This thesis delves into these issues from a sustainable perspective, aiming to understand the underlying causes and propose effective solutions with the research question: How can construction site planning contribute to a sustainable construction process?

The construction phase of the building utilizes 99% of the materials (Hoxha, et al., 2024) and more than 10% of that will end up as waste (Indenrigs- og Boligministeriet, 2021). Since 1982 there has been built and constructed an average of around 7.7 million m^2 annually in Denmark alone (Hoxha, et al., 2024). Construction sites are increasing in size and complexity, as larger sites prerequisite longer construction time and more actors on site, resulting in higher risk of complications and conflicts (Agarwal, et al., 2016). 30% of the problems could be attributed to subcontractors, 15-20% to the suppliers, and 10-15% to the designers. Thereby indicating that the cause of the issues arising during construction should primarily be found in preceding phases such as planning (Bertelsen, 1993).

In past decades the construction sector has become a massive CO_2-emitter, which is the main discourse in the Danish National strategy of Sustainable Construction that seeks for sustainable development (Indenrigs- og Boligministeriet, 2021). We acknowledge the significands of the industry footprint, yet we do not want to contribute further to the discourse of CO_2-emmisions as the measuring unit for sustainability. Instead, we look to broaden the understanding of sustainability in the sector to a holistic approach.

The construction sector consists of different planning paradigms. Lean Construction and its relations to environmental sustainability is explored by Francis & Thomas (2019) who finds corelations between the effeincy of Lean and reduced waste production. Furthermore, advocates for construction site planning point to the digitization of the sector as the solution (Værdibyg, 2021; Lean Construction-DK, n.d.; Dansk Industri, 2024; Indenrigs- og Boligministeriet, 2021), but it does not add up when projects keep having delays and exceed budget (Hansen, et al., 2021). Collaboration amongst sector

professions get worse (Mielke, 2024), and there is a significant skepticism and mistrust amongst the involved actors (Arkitektforeningen, 2023; Dansk Industri, 2024).

Actor Network Theory is used as the epistemological approach to scientific research, where the work; Where are the Missing Masses by Latour (1992) is used as the analytical grip. Observations and interviews have laid the background of much of the empirical data alongside with desk research. We will combine the sustainability perspective of the planning processes by studying the programs and anti-programs for ordering a field of complexity and chaos. Overall, this approach contributes to the field of sustainable design engineering by advancing the definition of sustainability within the sector and reconfiguring the socio-technical network of actors in construction site planning.

This thesis is in three parts, where the first part focuses on the existing field of study, the planning devices and how current discourse in the sector is related to sustainability. In the second part we analyze how planning devices are comprehended in a socio-technical network of many different actors, and lastly ending this paper with a designment drawing on the empirical study.

3. STATE OF THE ART

In the field of construction site planning in Denmark, a state of the art is here presented. This review states to uncover relevant literature before this thesis to assess the singularity and will be the foundation for the research question and research.

In 2023 seven million square meters of commenced construction filled the Danish landscape (Danmarks Statistik, n.d.; Hoxha, et al., 2024). Simultaneously with multi-dwellings being predicted to become a larger share of the built environment (Hoxha, et al., 2024), the size of single-family homes in 2022 set a new area record of 213 square meters per household (Boding, 2023). While one might expect a reduction in overall construction activity due to increasing demands for climate responsibility, the trend in Denmark indicates a shift towards larger construction sites.

Sections 161-165 in the Danish Building Regulations (BR18) concerning the Construction Site and Execution of Construction Activities stipulate that the layout of the construction site must be designed to ensure proper waste management (Bygningsstyrelsen, n.d.). This directive, while providing a broad guideline on site arrangement, does not elaborate further on specific expectations related to waste management and the planning of construction site and project processes. The term "responsible execution" is invoked, which permits a considerable degree of discretion for the developer, contractor, or construction workers involved. In a sector that is otherwise characterized by stringent regulation, there appears to be a notable allowance for interpretive flexibility regarding the planning and management of waste on construction sites. From 2023, BR18 require Life Cycle Assessment (LCA) documentation for the climate impact of new constructions, with specific CO_2 limit values for buildings over 1000 m^2 (Videncenter om Bygningers Klimapåvirkninger, 2024). The regulations, which will be further tightened and reassessed from 2025, focus on the building's lifecycle without directly addressing the construction site's operations (Social-, Bolig- og Ældreministeriet, n.d.), leaving room for interpretation in environmental management during the construction phase. To assess the environmental impacts from the construction site, BUILD from Aalborg University undertakes detailed analysis from 52 construction sites in Denmark (Kanafani, et al., 2023). Taking expected lower emissions from the Danish energy system 2025, the construction site is calculated to be responsible for 13% of the life cycle emissions of new buildings. In the report, construction waste is shown to have the biggest impact in on site operations, which constitutes 38%. Taking the regulatory changes

and the impact from the processes of the construction site into consideration, focusing on the improvements for sustainability at the construction site is a relevant topic to investigate.

The complexities and challenges of construction site planning has been a topic of investigation for decades (Bertelsen & Koskela, 2004). Construction sites are increasing in size and complexity, as larger sites prerequisite longer construction time and more actors on site (Agarwal, et al., 2016) To order the complexities and larger construction sites, planning devices have been developed to structure and facilitate the construction processes. The lack of construction site planning in Denmark was already identified as a problem in 1992, when a project on construction site logistics among others investigated the major reasons for inadequate material management: Insufficient work and supply planning (Bertelsen, 1993). The research by Wang et al. (2019) shows that budget and delays in construction projects is still an ongoing issue. Furthermore, the research states the lack of research in the construction phase and more specifically on energy efficient planning. To address this gap, the research develops a green performance evaluation system for construction site planning (Ibid.). The study proposes a sustainability-focused evaluation system for construction site planning to address environmental impacts, with its broader applicability yet to be demonstrated. It furthermore suggests more quantitative items for evaluating the sustainability of the construction site to ensure objectivity. As construction sites consist of dynamic elements and complex processes, they are all situated environments changing from site to site. Therefore, generalization and standardization might reduce the specificity of processes needed for successful construction site planning. This point is also evident in the study by Lindhard et al. (2023).

Diving deeper into material waste on the construction site research by Lindhard et al. (2023) is investigating the challenge of accurately predicting construction waste generation within the Danish context, critiquing the efficiency of existing waste management models. It highlights a gap in the accurate estimation of construction waste, pointing out the discrepancies in predictions for similar projects and the complexity of models that hinder their practical application. It emphasizes the need for improved waste estimation methodologies that account for the unique, dynamic factors of construction projects and suggests that existing models, often developed in different contexts, may not be directly applicable to the Danish construction sector. The study discusses the potential of BIM to enhance waste prediction and management. Building Information Modeling (BIM) can provide detailed information on material quantities and types, aiding in more accurate waste estimation. However, it is noted that BIM is rarely used in a waste management context on-site, suggesting a gap between technological capabilities and practical application. Though BIM is suggested as an approach

for the future of construction (Agarwal, et al., 2016), in terms of the need for an approach that is able to handle dynamic layout planning, BIM might not always be the best as the method requires large data sets. As noted by Lindhard et al. (2023), using BIM on the construction site might require a new actor on site who is able to use the method, and this might lower feasibility for the implementation of digital planning practices. These critiques are also evident in the study of Karmakar et al. (2022) and Yang et al. (2021), where BIM is used to create efficient planning, but lack scalability to other projects and construction sites. BIM can be seen as part of a newer digitization paradigm of the planning process that has difficulties as the construction sector has seen slow adoption of technologies, which has led the sector falling behind others in terms of productivity (Jacobsen, et al., 2024).

Another paradigm of construction site planning is the Lean Construction approach, which is a western interpretation of a Japanese production philosophy (Bertelsen & Koskela, 2004) that builds on the notion of seven waste streams: Transportation, waiting, overproduction, defects, inventory, motion and extra-processing (Francis & Thomas, 2019). Francis & Thomas (2019) points to a relation between Lean Construction and environmental sustainability mainly due to the efficiency of production. Bertelsen & Koskela (2004) states in their work beyond Lean Construction that construction sites are more complex production system then the assembly line. The many unforeseen obstacles, such as weather, and can therefore not be translated directly into the construction sector.

Cooperation within a multi-skilled ad-hoc teams (Bertelsen & Koskela, 2004) or partnering (Nyström, 2007; Værdibyg, n.d.) has gained more attention in the sector and is seen as a tool for optimizing the construction process by creating mutual understanding and relationships. Initiatives as early involvement of the actors to set common goals and thereby create trust among the team members is key to this concept (Nyström, 2007). Furthermore, the partnering framework suggests two phases with early involvement of multiple actors and cooperation of the planning process. The partnering framework still comply with the contractual framework for building contracts (Dansk Industri, 2005). Love & Smith (2019) emphasizes that almost all construction projects are newly formed networks of actors, and that this field of study is rather understudied in the sense of why rework occurs.

Planning paradigms like the digital BIM, Lean Construction, and Partnering is crucial for advancing construction site planning and sustainability. Understanding these paradigms is essential for grasping the current methods of construction site planning. This knowledge is vital when designing new solution spaces for planning devices to ensure they address existing challenges, leading to sustainable and productive outcomes in the construction sector.

To accommodate a more detailed and situational approach we address this research gap, by looking at a perspective with more qualitative qualities. The study by Tryggestad et al. (2010) examines the construction management literature's view on project goals, advocating for a dynamic understanding that integrates the transformative role of non-human actors and actor-network theory. It emphasizes the process through which design ambitions evolve and are materialized in construction projects, illustrated by the case of a skyscraper construction. The study highlights the importance of adapting and redefining project goals as material and social factors interact, suggesting practical implications for construction project management and evaluation. This approach advocates for flexibility and iterations in managing construction projects, moving beyond rigid goal-setting practices to accommodate the complexities and uncertainties inherent in construction processes. Tryggestad et al. (2010) furthermore suggests a paradigm shift towards flexible, iterative planning processes that consider the transformative interactions between material objects, technology, and human actors. By integrating ANT and emphasizing the adaptive redefinition of project goals, this research project positions itself to address the complexities and uncertainties of construction site layout planning in a novel and impactful manner, but also to contribute valuable insights and methodologies that can be adapted to broader contexts within the construction sector.

In conclusion, the state of the art has unveiled significant gaps in the field of construction site planning within the Danish context. Notably, the underexplored areas are:

- Sustainable initiatives for the construction site
- Sustainability as more than CO_2 due to the complexities of the construction site
- ANT as a theoretical approach for construction site planning

These highlight the pressing need for further research and practical solutions tailored to a unique network of actors in construction site planning.

3.1. WHY IS ON-SITE PLANNING SUSTAINABLE?

When studying sustainability in Danish construction, it is most important to define what sustainability means and thereby what goals we seek. In this research, the concept of sustainability is examined within the context of the Danish construction site planning existing in the frames regulated both by EU regulations and the Danish Building Regulations from 2018 and last reviewed in 2023 (Social- og

Boligstyrelsen, n.d. a). This focus is driven by recent regulatory changes (Social- og Boligstyrelsen, n.d. b), notably the BR18, which have signified the importance of environmental considerations in the sector. Therefore, it is relevant to understand what sustainability entails from these regulatory entities and thereby how the sector must follow these goals. The latest mention of a sustainable strategy for the construction sector from the EU can be found in the strategic foresight report from 2023 (European Commission, 2016). The strategy mentioned in this report can be found in much more detailed in the brochure for European construction sector, by the European Commission 2016:

From this somewhat detailed, yet not practical oriented definition of what sustainability in the European construction sector means, it is evident that sustainability comes from a competitive drive across actors in the sector. This definition ultimately leaves each country to evaluate how much focus should be placed on environmental, social, or economic sustainability. One thing that is clear is the assessment of reduced environmental impact by implementation of LCA. This can be seen in the Danish regulations, which implemented LCA requirements for new buildings in 2023 (Social- og Boligstyrelsen, n.d. b).

A study conducted by Kanafani et al. (2023) reveals that a substantial 38% of emissions emanating from construction sites can be attributed to material waste. The Danish National Strategy for Sustainable Construction states a significant amount of waste in the sector and furthermore define waste as both time waste, inefficient working processes and lack of coordination that can all lead to material resource waste (Indenrigs- og Boligministeriet, 2021). This approach of valuating waste in material resources we find too narrow and insufficient. The waste definition needs to be unfolded into more entities to be studied. Hence this study draws upon the seven streams of waste principle from Lean Construction, that Francis & Thomas (2019) unfold and put into a sustainability perspective.

The seven streams are: *transportation* due to the lack of logistic planning, flow problems that lead actors to *waiting*, *overproduction* of goods, *defects* in the drawing material or building components, overstocking of *inventory* creates space issues, poor planning leads to excessive *motion* and *extra-processing* in the form of resources. This broader notion of waste is more accurate for the project. It does not only focus on the emissions of waste but rather on the unnecessary processes that cause waste. The definition of unnecessary processes is based on the framework of Lean Construction. This term of waste will hereafter be named holistic waste to accommodate both material and immaterial waste. The notion and importance for material and immaterial waste will be unfolded on the grounds of ANT (Chapter 7).

3.2. RESEARCH QUESTION

The field of construction site planning and sustainability encompasses a wide range of topics and considerations. To ensure the feasibility and relevance of this thesis, specific delimitations have been established and the focus is the underexplored topics seen in the state of the art:

- Sustainable initiatives for the construction site
- Sustainability as more than CO_2 due to the complexities of the construction site
- ANT as a theoretical approach for construction site planning

The research and design focus on producing practical and useful design suggestions for professionals engaged in construction site planning development. By narrowing the scope based on relevant topics identified in previous state of the art and measures of feasibility, the research aims to address key issues in a meaningful way. This focused approach will help in answering the research question:

This project is aimed to get an understanding of how sustainability in terms of holistic waste can be incorporated in the planning devices and ask the question of how a construction site planning device can create sustainability in a sector with many divergent actors who enlarges the complexity of the process.

4. RESEARCH DESIGN

The research design is portrayed a methodological view of the double diamond model (Design Council, n.d.) (Figure 1) focuses on answering the research question: "How can construction site planning contribute to a sustainable construction process?" The model is divided into two main phases, each represented by a diamond shape, symbolizing the divergent and convergent stages of the design process.

The sub questions of the research question are used as an analytical research approach, where the first sub question (What is sustainability in the planning process of the construction sector?) is unfolded in the state of the art (Chapter 3). The second sub question (How does the utilization of insights from programs define room/space for design optimization of a construction site planning device?) is explored in the analysis (Chapter 7), as seen in the first diamond in the figure below. The last sub question (How can a construction site planning device be designed to foster sustainability on site?) is explored in the design chapter (Chapter 8), which represents the second diamond in the figure below.

4.1.1.1 FIRST DIAMOND: UNDERSTANDING AND DEFINING THE PROBLEM

In this initial phase, desk research, expert interviews, and observations gather insights into current construction sector programs and site planning. Expert interviews and on-site observations provide qualitative data and practical insights. The goal is to identify relevant actors, their sustainability initiatives, and construction workers' responses. The data is then analyzed to formulate programs of action, defining key areas for integrating sustainability into construction site planning and identifying elements and processes that can be optimized for sustainability.

4.1.1.2 SECOND DIAMOND: DESIGNING SPACES FOR SOLUTIONS

This phase translates the programs of action into specific design functions, brainstorming potential solutions to address identified improvements. These functions outline how sustainability can be implemented in construction site planning. The final phase involves developing a concrete design

proposal using a morphological chart, systematically comparing design elements and their impact on sustainability. The result is a design proposal chart to guide future planning device iterations.

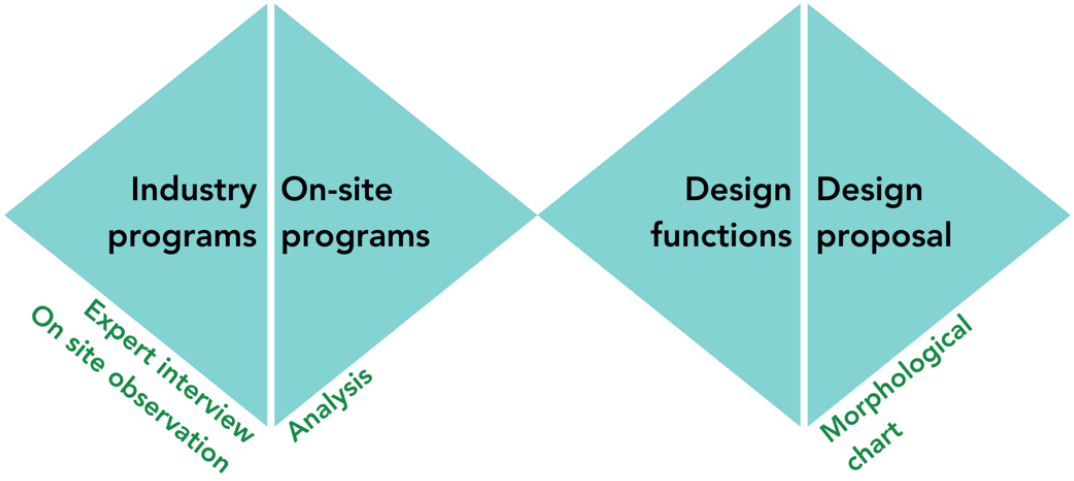

Figure 1: Visualization of research design

This double diamond model addresses the research questions (Figure 1). It explores what sustainability means in the planning process of a construction site by examining current programs. It defines how insights from these can be used to optimize the design of a construction site planning device. Ultimately, it focuses on how such a device can be designed to ensure that construction site plans are realized as intended and sustainable actions on-site are implemented.

5. ACTOR NETWORK THEORY

This chapter examines Actor-Network Theory (ANT) as a theoretical framework for understanding how construction site planning can contribute to a sustainable construction site process. Moreover, we seek to understand how it is possible to create order in the complex and self-organized network on the construction site, as this form of order must be present to foster realization of construction site plans. It is through this theoretical lens, this thesis explores planning activities that accommodate the interactions of actors to enhance sustainability in construction and is grounds for the research and scientific perspective of this thesis.

The constructivist perspective in the philosophy of science, which emerged prominently in the 1960s with Thomas Kuhn's "The Structure of Scientific Revolutions", argues that scientific knowledge is not simply uncovered but constructed (Jensen, 2014). This view shifted the understanding of science from a linear progression towards truth to a more complex, socially embedded process. Building on these ideas, Bruno Latour and other scholars developed ANT, which further blurs the lines between the social and scientific, by positing that all elements in a network — humans and non-humans alike, also called generalized symmetry — are actors that influence and shape responses and outcomes (Jensen, 2014; Sjørslev, 2015).

ANT – a prominent framework within Science and Technology Studies (STS) – effectively integrates scientific understanding and sociological insights on interactions among scientific, technological, and social elements. This socio-technical network provides a comprehensive approach to tackle complex challenges in the construction site planning presented in this thesis. The integration is crucial for fostering sustainability, as it encourages a holistic view of construction sites as dynamic systems where each decision or change can ripple through the network and alter outcomes. In this way associations amongst actors are created to establish order in the network. Strong associations can dominate a network and align actors for a common purpose, which in the case of creating sustainable change is an important matter.

Ontologically, ANT adopts a flat and non-hierarchical perspective, suggesting that all entities (actors) in a socio-technical network have equal potential to affect change (Sjørslev, 2015). This stance is radically different from traditional hierarchies where humans are seen as the primary agents of change, and non-human elements are merely passive. Epistemologically, ANT posits that knowledge is

not discovered, but rather constructed through the interactions within a network. This construction is influenced by the continuous negotiations among all actors involved (Sjørslev, 2015). While Latour does not address "planning" in the traditional sense, his approach is applied to understand how planning operates in various contexts. In the same way as Latour and ANT unfolds the complex social, material, philosophical, linguistic, and technological aspects of the emergence of science, we seek in this thesis to unfold the many complexities of the construction site, regarding planning.

5.1. LATOUR'S SHIFT FROM KNOWLEDGE TO DESIGN

Throughout Bruno Latour's contribution to ANT, he has progressively shifted his focus towards the domain of design. This transition reflects a broader movement in his work from studying how scientific facts – in Laboratory Life: The Construction of Scientific Facts (1986) – are constructed. To exploring how design influences and shapes human and non-human interactions – Where are The Missing Masses: Sociology of a Few Mundane Artefacts (1992). These are two examples of which his literature points to his objects of interest. Latour argues that design is pervasive; everything from laws to buildings and digital platforms are designed, and thus, subject to change and improvement (Latour, 1992). This shift recognizes design as a key component in shaping societies and advancing technological and social innovations.

Latour views design not merely as an aesthetic or technical activity but as an integral process of assembling, or what he terms "composition". Unlike modernism, which often promotes a unidirectional progression towards technology and industrialization without regard for environmental consequences, compositionism advocates for a mindful, responsible assembling of our world (Latour, 2010). This approach emphasizes the responsibility of designers (broadly defined) to consider the implications of how things are put together — the systems, interfaces, and infrastructures — and how these designs affect actors constituting a socio-technical network.

5.2. PROGRAMS OF ACTION

In the essay, *Where Are the Missing Masses? The Sociology of a Few Mundane Artifacts* (1992), Latour contributes to ANT by describing how relations enable us to influence others with the goal of fulfilling our desires. This thesis focuses on evaluating construction site planning, hence the epistemology and methodology described in the essay by Latour (1992), is relevant. It presents an analytical approach to understanding how construction site planning devices have evolved through interactions over time and their impact on planning. The role of non-human actors is acknowledged, showing that design laws constrain interactions. Latour explores how non-human actors' design can direct human action and behavior. He illustrates how technologies - in this case a planning tool - can act compelling certain actions and shaping decision-making processes (Ibid.). Looking through this lens that Latour is presenting we will seek to analyze the development of concepts for construction site planning.

The concept of a 'program of action' describes an arbitrary actor initiating an action, met with an anti-program's response. Anti-programs are met with a new program continuing the design iteration for the program of action. Understanding this interplay between artifacts, programs of action, and opposing anti-programs illuminates the complexities behind planning attempts for construction sites. Latour illustrates this dynamic with a practical example: the design of hotel keys with aim for their return after use - a program of action. Initially, the hotel manager wants guests to return keys to the reception upon departure. When this order is not followed by the guest, a new program emerges, as the hotel manager sets up a sign at the reception (Ibid.). The sign does not fulfill the program of action thus the manager proceeds with another program; attaches a bulky wooden key hanger making it uncomfortable to carry. This iterative process continues until the program aligns with the program of action - the hotel managers goals. Creating strong alliances through non-human actors in a chaotic network, such as creating sustainable changes on a construction site, can be seen as frustrating and unmanageable, but the theoretical framework of Latour establishes a manageable method for ordering these elements.

In this analysis, we will trace changes in Danish construction site planning concepts aimed at solving inefficiency and creating order. Using Latour’s framework of programs and anti-programs, we aim to analyze these elements in construction site planning.

6. METHODS

In the following chapter, methods used for the thesis are presented. The methods of desk research, expert interviews, and observations are chosen on the grounds of ANT and more specifically Bruno Latour's work on programs of action (1992) as they complement the theories notion of actors and their constructivist network through situated relations. Through these methods we wish to explore the construction site planning and the experts are chosen and interviewed due to their attempts on making order on the construction site or through construction site planning. Furthermore, field observation on construction sites is conducted to elaborate and secure the validity of empiric findings through the expert interviews.

6.1. DESK RESEARCH

To conduct a comprehensive and efficient literature search for this thesis, the method of block searching was employed. This approach involved organizing search terms into thematic blocks covering various aspects of construction site planning and sustainability, ensuring a thorough exploration of relevant literature (Drejer, 2023).

The process began by defining specific areas of investigation, followed by identifying relevant keywords and organizing them into thematic blocks, including synonyms and related terms to broaden the search scope. Searches were conducted using academic databases such as SCOPUS, focusing on literature from 2017 to 2024. Specific strategies, like combining keywords (e.g., "building site OR construction site"), were used to refine results. The most pertinent articles were selected based on their relevance, credibility, and contribution to understanding sustainable construction site planning. The selected literature was synthesized to inform the research framework and guide the thesis's subsequent stages, including the co-design workshop and planning device development.

By employing block searching, the research ensured a comprehensive and organized literature retrieval process, facilitating the identification of key insights and supporting practical design suggestions for sustainable construction site planning.

6.2. EXPERT INTERVIEW

In the process of analyzing planning programs on the construction site, expert interviews are employed as a qualitative methodological approach. Expert interviews are a specialized form of interview that require a well-considered approach to effectively acquire the rich knowledge held by experts. According to Döringer (2020), expert interviews should balance thorough prior research with non-biased curiosity to ensure the elicitation of valuable insights. The expert's knowledge surpasses common understanding, so the interviewer must be familiar with the subject to avoid basic explanations. If the interviewer is too novice, rapport may not be established, compromising data quality. If the interviewer knows too much, curiosity may be lost, leading to incomplete data. These precautions are observed to ensure robust empirical data collection for this thesis.

The construction sector consists of many siloed companies. Therefore, the experts interviewed for this thesis cannot fully represent every perspective. To mitigate this, experts were selected based on previous research and referrals from academic and personal networks. This selection strategy aligns with Döringer (2020) emphasizing on theoretical sampling and the importance of identifying individuals whose perspectives are recognized within the sector. By interviewing experts whose viewpoints are well-known, it is assumed that their narratives will resonate with or contrast against those of others in the field, thereby highlighting significant perspectives in the research. In the following chapter the conducted interviews are presented chronologically, with descriptions of relevance for this research and a summary. All expert interviews are themed coded in the software NVivo[1]. The data-driven coding method is used to analyze qualitative data, ensuring themes are identified rather than relying on personal interpretations of interview relevance (Kristiansen, 2020). All interviews were transcribed, using an AI transcription tool[2]. The transcription ensures a more objective analysis. Coded interviews and themed citations are in Appendix 1 and will be referenced by name in the thesis.

[1] Lumivero.com

[2] Goodtape.io

6.2.1. ACADEMIC RESEARCHER

25.02.2024

In the research paper Strengthening the Danish Construction Innovation System (translated to English) (Thuesen, et al., 2011), Christian Koch amongst others are writing about the different schools of planning in the Danish construction sector. Koch has been researching in the planning aspects of construction for more than 20 years and is now working as section leader at Civil and Architectural Engineering at the University of Southern Denmark.

6.2.2. LEAN CONSTRUCTION EXPERT

08.03.2024

To understand Lean Construction and the tails about the planning approach outside of scientific research, it was relevant to interview an expert on this field. Therefore, an expert interview with Morten Skaarup Jensen Senior Project Manager at Værdigbyg and Project Manager at Lean Construction-DK (Værdibyg, n.d.) was relevant for the thesis. Jensen explained how the most popular and innovative Lean Construction tool in Denmark is Tactplan.

6.2.3. PLANNING DEVICE EXPERT

19.03.2024

We sought it be relevant to execute an interview with Tactplan[3], which is developed by the company Exigo [4], to understand their planning tool better and the positives and difficulties they have met. It is important to note that the feedback about the tool comes from clients who have invested in planning facilitation. The expert interview with Martin Veis aimed to investigate why construction site planning remains problematic despite the prioritization of tools like Tactplan.

[3] Tactplan.com

[4] Exigo.dk

6.2.4. PLANNING CONSULTANT

25.03.2024

During an interview conducted at the engineering company ABC Consulting Engineers, insights were gathered from in-house advisors specializing in sustainability, fireproofing, structural engineering, and project management. Rasmus Berthelsen, a project leader with several years of experience in the construction sector unfolded the consulting perspective of the construction site planning.

6.2.5. DIGITIZATION EXPERT

02.04.2024

Until now we have learned that on the construction site, it is mainly the schools of Lean Construction and digitization are the dominant paradigms. Therefore, an interview with Ole Berard is relevant. He has 20 years of experience in the construction sector and is currently head of digitization at the unifying knowledge center for the Danish construction sector Molio, responsible for buildingSmart, internationals standards and ConTech Lab (Molio, 2024)

6.2.6. ACADEMIC PROJECT MANAGEMENT EXPERT

30.04.2024

Planning processes in the construction sector is a field there has been studied by Aarhus University and Søren Wandahl. Wandahl studies correlations between work environment and construction management and navigates amongst others in the field of social science. Sustainability and planning are newer themes that this interview gave insides about.

6.3. PARTICIPATING OBSERVATION

Gaining a comprehensive understanding of a topic and field necessitates both acquiring knowledge from experts and the environments of the relevant actors. Elaborating on the expert interviews it was notable how there is a (non-confrontational) conflict between the planning engineers and the contractors. Therefore, we deemed it essential to experience and observe both environments firsthand to fully understand their dynamics and significance. In order to do so, we conducted participating observations. The oxymoron term and method are an insightful way of collecting empirical material while also feeling the environment of the actors. The participating observation can be categorized as a qualitative method that focuses both on human and material aspects related to social practices (Szulevicz, 2020). Frequently, tacit and crucial knowledge is overlooked in interviews, where language is used as the primary knowledge mediator. Native norms and values, being ingrained and implicit, often go unmentioned because they are invisible to those within the culture. However, when an outsider investigates a different culture, these concealed aspects become more apparent. This newfound visibility can help explain and address complex issues within the field of study. Hence the method of participating observation adds to the details and empirical material for this thesis.

The following chapters will briefly describe the observations, which can be found in Appendix 2 and 3.

6.3.1. CONSTRUCTION SITE (ANONYMOUS)

12.10.2023

This observation was made prior to the start of the project at a larger construction site based in the northern Zealand. The site is interesting due to the limited space and possibilities to store materials and machinery on the construction site. Due to anonymity descriptions are not included in the Appendix.

6.3.2. THE EFFECTIVE CONSTRUCTION PROCESS CONFERENCE

08.03.2024

BAT is an organization of seven unions in the construction sector (BAT, 2024). The BAT cartel, as the official name is, hosted a conference with keynote speakers from academics and the executing phase of construction about retrospective views and perspectives on the efficient construction process. The presenting experts on construction site planning was (Rolf Simonsen, Søren Wandahl, Christian Koch, Henrik Mielke, Søren Elkjær, Hasse Neve & Mads Okking). These actors also represent an expert viewpoint form the planning phase.

6.3.3. CONSTRUCTION SITE (DSB NÆSTVED)

09.04.2024

The observation is conducted at a construction site, focusing on the interactions among various human and non-human actors. Observations were systematically recorded to capture real-time responses to planned actions and noted resistances, providing a detailed account of the dynamics at play during the construction process.

6.4. MORPHOLOGICAL CHART

In the design work, the morphological chart method will establish essential design aspects by creating design parameters. By focusing on individually separated functions rather than components, the outcome should better address the comprehensive functionality of the product (Cross, 2008).

The process begins with identifying the functions to be designed for. The feasibility of these functions is crucial, as it ensures that proposed solutions are practical and can be implemented effectively in real-world scenarios. Once the functions are listed, brainstorming subsolutions for each individual function is the next step. This creative phase involves generating multiple ideas and potential solutions for each function, resulting in a comprehensive chart with a variety of options for each requirement. This approach encourages divergent thinking, allowing designers to explore a wide range of possibilities without immediate constraints. This identification is guided by the programs of action based on the analysis, which provide a framework for understanding the necessary functions

and their relevance. After generating subsolutions, the next phase involves combining these subsolutions into cohesive design ideas. This step is critical in transforming individual functions into integrated design concepts. The design concepts should be based on the situational aspects of a specific network; hence this step is not included. It is instead recommended for relevant actors to continue the design work. This way, the selected design functions, which aim to highlight order and sustainability on the construction site, are implemented in the most functional manner for a specific planning device. By systematically exploring different combinations of subsolutions, designers can identify the most effective and innovative approaches to solve the design problem.

The morphological chart method supports ANT as the theory analytically explodes networks into smaller bits to understand the intricate interactions and relationships within a system. The morphological chart complements this by systematically putting these bits together again, creating a coherent and functional whole. This combination allows for a deeper understanding of the complex networks involved in construction site planning and enhances the ability to design solutions that are both comprehensive and practical. The morphological chart method offers a structured framework for managing the complexity of design tasks in product design to explore the design space and to identify novel subsolutions of a product, by ensuring that relevant aspects are considered and functional (Cross, 2008), and it aids significantly in the exploration and resolution of the design space.

7. ANALYSING CHAOS INTO PROGRAMS

The following chapter presents the analysis based on the theoretical work of Latour. This analysis investigates the initiatives and responses for construction site planning, with the goal of understanding why planning initiatives and -tools are not effectively used, addressing the second research sub question: How does the utilization of insights from programs define a space for design optimization of a construction site planning device? Firstly, the analysis looks at the industry programs, that exists due to regulations and contract forms. These programs are relevant to understand the frames within the constructed networks on the construction site. Complementary, the analysis dives into the actors on the construction site unfolding a more situational aspect. The findings from the analysis are translated into design functions for optimization of planning tools, which is presented in chapter 8.1.1. These combinations of general sector framing programs and specific on-site programs ensures a realistic overview of the feasible solution space for sustainable changes.

7.1. INDUSTRY PROGRAMS OF ACTION

In this analytic part we will unfold the programs of the human and non-human actors and broaden their perspectives and relations of industry programs. A sector that is described as rigid and where laws and regulations is hindering more sustainable initiatives to arise (Gottlieb, 2023; Værdibyg, 2021). Firstly, the actor network is described to establish an understanding of the relevant industry actors framing the construction site planning. Following this chapter the analytical regulatory programs are presented. These programs are established different than the on-site programs, as they are regulatory and therefore forced. Yet, some antiprograms are still present, highlighting the self-organizational chaos of the construction site.

7.1.1. DESCRIPTION OF THE ACTOR NETWORK

In the following chapter the actor network of a general construction site planning is explored. Due to the complexities existing in the network (Bertelsen, 2003; Værdibyg, 2021; Hansen, et al., 2021) it is relevant to understand the socio-technical network framing the programs and anti-programs on the construction site.

There is a narrative in the Danish construction sector that it is split into silos and that the relations between actors are under a constant pressure due to reasons of contractual bindings and regulations (Arkitektforeningen, 2023; Hansen, et al., 2021). The different contract forms influence the configuration of the network of actors. The client is the owner of the project, the contractors are the main responsible for the construction of the project and sub-contractors are hired by either the client or the contractor (Dansk Industri, 2024). The sub-contractors are divided into very specific trades, such as painter, electrician or carpenter, that work in their own organization. Furthermore, the sector has a fairly large number of unions and organizations that represent different interests and serve the benefits of their own organizations or unions to improve conditions for the members (Dansk Industri, 2024; BAT, 2024; Bygherreforeningen, 2024). Collaboration in the sector has gotten worse (Mielke, 2024) and actors are drifting further apart. With larger projects the number of actors increase significantly, since the Danish construction sector mainly consists of Small and Medium-sized Enterprise (SME) with more than 90 percent of the enterprises having less than ten employees (ConTech Lab, 2023), this complexifies the actor network.

In studies and reports the client is seen to be the decisive and leading actor of driving the project (Gottlieb, 2023; Værdibyg, 2021) and clients show divergent willingness to risk in projects (Gottlieb, 2023). Værdibyg (2021) emphasizes the importance of an active client when implementing sustainability in the construction process. Consultants are the managers of feasibility in a project (Byggeproces.dk, n.d.) and the mobilization of knowledge (Værdibyg, n.d.).

The framed network of the construction site has proven to involve complex networks of professions existing in smaller enterprises with individual and divergent interests. The construction sector is larger than described, and it will be very rude to arrange only the human actors in a network and then analyze their relations. The non-human actors, such as planning technologies or devices, that mediates the relationships in a field are crucial (Latour, 1992), and will be explored in the following chapter.

7.1.2. INDUSTRY PROGRAMS

In the following analytical chapter, we will describe the dominant industry programs for ordering the construction site planning. We will identify the programs off non-human actors that are initiated and implemented by regulators in the construction process.

A non-human program of ordering is a model of the construction process reductionized into a visualization shown in Figure 2. Manageable sections are by chronologically time lining the process into general phases: programming-, proposal-, project-, execution-, and operational phase. The construction phases work as a device to control the human actors in the assumption that they are perfect and follow the rules of the program. Phases of the construction process is described in five or six phases, where the boundary of a new phase indicates new configuration of actors. Each phase mobilizes different actors in the network which can lead to complications and controversies. Hansen, Søder, & Fredslund (2021) emphasises that the boundaries between phases and the involvment of new and different actors may cause less transparency of the process, communication issues and obligations amongst the complete actor network. In many cases the progression to another phase happens prematurely due to timepressure or other factors (Appendix 2). This creates uninteded open processes such as drawings that are not completed for the construction workers, which leads to wasted time. Waste amongst construction workers, due to insufficient planning of the project from consultants, is already at stake. As a result of poor communication and information the workers must delay assignments or other planned processes.

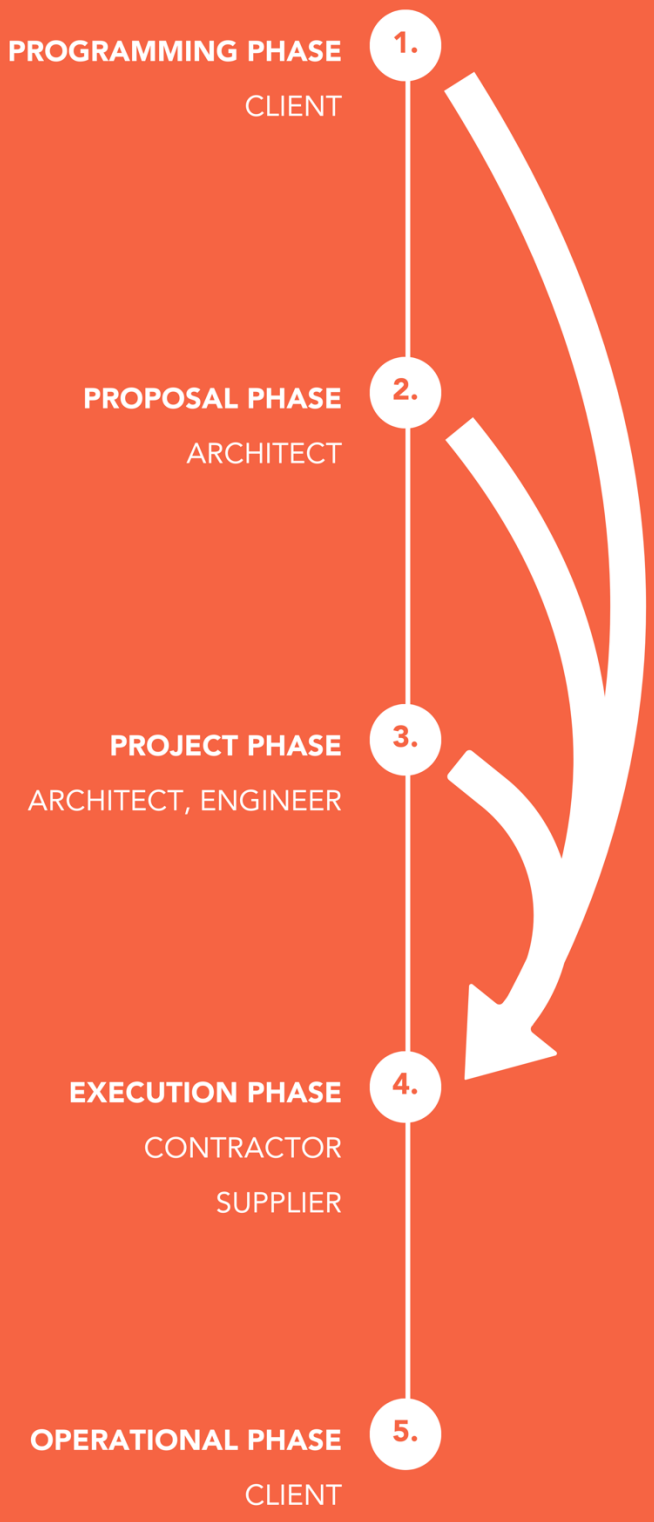

Figure 2: Visualization of the construction phases and the unintended dragging of open ends. Unfinished processes can influence execution phase where the conflicts become visible (visualized by the arrows). Inspiration from Bygningsstyrelsen (2019)

A contractual program of the Danish construction sector is the General Conditions for Building and Construction Works and Supplies (AB18) formulated by the Building Council (Bygningsstyrelsen, n.d.). It dictates the contractual relationships, meetings, and the legal responsibilities between the actors involved in a construction project. Since the implementation of AB18 in June 2018 there has been a stagnation in the number of arbitral cases at approximately 350 cases a year, with a peak in 2021 at 396 (Voldgiftsnævnet, 2024). In other words, the regulations and clearer rules in the area has not led to less controversies between the actors.

The contract forms, as a non-human program, frame the responsibility of the actors and differ mostly in the terms of responsibilities for the sub-contractors, but also the legal terms of the project. There has not yet been seen any relations between the form of contracts and the amount of waste generated in the construction process (Hansen, et al., 2021), but the contracts do have an impact on the planning process of a project (Gottlieb, 2023). The main and turnkey contractor bear the responsibility towards the client and furthermore the responsibility of the subcontractors (Dansk Industri, 2024). The extent of the work that the subcontractor must perform for the other contractor depends on the specific agreement between the parties (Bygningsstyrelsen, n.d.). Furthermore, main- and turnkey contracts is the most common contract forms in construction projects in the year 2022 with 86% of the market share (Byggefakta, 2023). The contractual non-human program prescribes order and orderly behavior in the otherwise completely chaotic process of delegating responsibility of flaws and failures amongst human actors. We can only imagine how it would be without this program. Interestingly, Gottlieb (2023) points out that the institutionalized regulations and contractual foundations hinder organizations to work sustainable.

The planning paradigms and frameworks can be seen as programs to order the construction site. In the early years of Lean Construction there has been a rigid focus on the correct use of theoretical terms, which has led to many conflicts and separations between the contractor and site planner. Nevertheless, not implementing the key components of Lean Construction or essential tools for the planning process is a key issue (Appendix 1).

Early involvement in the planning process tends to create a more organized process and less coalitions amongst the different actors. The project team seem to create more attachment to the particular project if they are involved in the planning and the time scheduling process. Partnerships in projects makes the planning process easier hence the previous common knowledge and relations between actors (Appendix 1 and 3). When the process is driven by an ambitious client with explicit

goals for the planning processes, the time scheduling and the general construction process is a more successful (Appendix 1).

Digitization has become accessible for the sector, but not yet implemented at same rate as in other industries. Within the paradigm of digitization, Lean Construction is the main approach for effective planning on the construction site, supported by digital tools. Digitization is great for standardization and automatization of processes and have a lot of potential in the sector. Yet, the construction sector is the least digitized (Appendix 1).

Overall, the analysis highlights the complexity of construction site planning and the interplay between non-human programs and human actors. Bridging the gap between theoretical planning and real-world application, enhancing communication, and adopting digital tools are essential for improving efficiency and sustainability in construction site planning. These programs are an attempt to create order in a construction process that operates in chaotic and incomplete network of environments. When designing for improved programs such as suggestions for sustainable planning devices this is the design framing, which is explored in the following analysis: On site programs of action.

7.2. ON SITE PROGRAMS OF ACTION

Empirical findings (Appendix 1) and findings from the state of the art (Chapter 3)underlines that while the notion of a sustainable construction site is conceptually appealing, practical implementation of strategies are notably absent. This gap suggests that before sustainability can be effectively integrated into construction practices, the fundamental processes of construction planning itself need substantial enhancement. Therefore, this analysis will explore the planning of construction sites as a prerequisite for enabling sustainable actions. The planning phase is critical as it sets the stage for all subsequent actions and decisions that affect sustainability outcomes. Issues such as holistic waste as unnecessary material and immaterial processes that causes waste, are prevalent and hinder the transition towards sustainable construction sites. It is noted that most initiatives for more effective planning, is coming from one part of the sector; the planning phase, which include the programming-, propose-, and project phase (Figure 2). The Danish construction sector can generally be divided into planning and execution phase (Grytnes, et al., 2018). This is very evident in the school system, where the actors of the planning phase are educated through higher education and the construction

workers etc. are in vocational training. Here it is evident that the planning initiatives (programs) comes from the planning phase of the construction sector and responses of these (anti-programs), from the execution phase.

As you read the programs for construction site planning in the following chapter the initiatives seem rather intuitive and productive; they make sense. Latour also points out the complexities of how networks form through actors, perceptions and relations makes it very difficult for a designer to expect and predict the responses of another actor if not aware of such complexities (Latour, 1992). This becomes much clearer when anti-programs are presented as they illustrate the different worlds existing in the silos of construction site planning.

7.2.1. PROGRAMS OF ACTION

The expert interviews revealed several strategic initiatives designed to optimize the efficiency and sustainability of construction site planning. The following programs of action are based on empiric material from planning engineers, who advocates for Lean Construction principles for better planning. These are listed below, in no particular order and can be found in appendix 1.

Weekly status meetings: These meetings are intended to enhance team involvement and accountability, providing regular updates on progress and aligning team members on activities planned for the upcoming week. This initiative aims to maintain a consistent rhythm and ensure that all actors are informed and engaged throughout the construction process.

Value creation across projects: By integrating planning processes across various projects, there are opportunities to standardize practices and leverage learnings from one project to another. This program aims to establish a unified approach that can increase efficiency by applying strategies universally.

Decomposing project overviews: Simplifying project plans into smaller, more digestible segments after an initial comprehensive plan helps in making the plans more understandable and manageable. This breakdown assists the construction worker, who are not equipped to understand nor interested in the cyclograms showing all project plans.

Engagement of committed clients: Focusing on clients who have a long-term interest in construction and are likely to undertake future projects encourages ongoing improvements and sustainable

practices. Such clients are more likely to invest in quality and sustainability, understanding that these elements will benefit their long-term property portfolio.

Development of digital tools: Crafting digital tools that embody proven planning methodologies can streamline the planning process, making it more accurate and efficient. These tools are designed to be intuitive and facilitate real-time adjustments, thereby enhancing the adaptability of project management on site.

Renaming methodologies: To avoid resistance from actors who may have preconceived notions against certain methodologies (like Lean Construction), renaming these methods can help in their adoption. This strategy seeks to rebrand the methodologies in a way that focuses on their benefits and compatibility with modern construction demands, rather than their historical baggage.

The effectiveness of such programs can often depend on the quality of their execution and the ability to engage all relevant actors. For example, while the standardization of processes can increase efficiency, it must not hinder the flexibility needed to handle unique project challenges. Similarly, the digitization of planning tools can enhance precision in project management but requires adequate support and training to ensure widespread usability. Ultimately, the success of these programs depends on strong associations and a balanced approach that considers both the strengths and limitations that these programs entail.

7.2.2. ANTI-PROGRAMS

The following anti-programs identified reflect the inherent resistances and challenges within the construction sector that could hinder the implementation of the programs presented in previous chapter. These anti-programs are perceived by planning professionals and these descriptions are therefore their interpretations. In the next chapter, these anti-programs are further investigated from the viewpoint of the construction site.

Contract disclaimer: A pervasive response on construction sites — and generally in the construction sector — is to use the contract as a disclaimer for responsibilities on the contractual matters regarding the construction site execution.

Contractors not prioritizing plans: The cyclogramic plan may not be relatable and of importance for the contractor, resulting in the plans ending in the bottom drawer. Instead, the contractor seeks habitual planning processes of the construction site.

Individual task focus among workers: Construction workers focusing solely on their specified tasks and often only one day ahead without considering the larger project context. This can lead to inefficiencies and conflicts in project execution.

Creation of unofficial buffer zones: When construction workers establish unofficial physical buffer zones due to premeditated congestion or other planning failures, it indicates a misalignment between the planned use of space and actual site conditions.

Pressure on contractors: Contractors often face pressure to complete projects quickly and cheaply, which can compromise the quality of the construction. This anti-program reflects a broader industry challenge of balancing cost, time, and quality between siloed professions.

Client acceptance of fault levels: Clients who accept a certain percentage of faults may undermine the drive for quality and precision in construction. This tolerance has led to a culture where minimal compliance becomes the norm, rather than striving for excellence and error minimization.

The anti-programs provide valuable insights into the obstacles faced in construction site planning but addressing them effectively will require comprehensive and regulatory changes within the sector. It is worth noting the gap and lack of interactions described from the viewpoint of construction workers and detailed descriptions from contractors. This gap will be addressed in the following chapter, where the programs and anti-programs are assessed and further unraveled according to observations on site.

7.2.3. THE CONSTRUCTION SITE'S POINT OF VIEW

To address the missing masses of actors in the executing phase we observe how these tails of planned action and resistance unfold on site. This chapter examines the practical implications of identified anti-programs in construction site planning, assessing how these resistances – and more – manifest through participating observations on site. Overall, all anti-programs previous described could be confirmed through on-site observation (Appendix 3).

The observations conducted at the construction site reveal additional anti-programs not explicitly outlined earlier. These emerged from the dynamic interplay of various human and non-human actors in the actual construction environment, highlighting the gap between planned procedures and on-site realities. In the following chapter the additional anti-programs are described below:

Resistance to change: Observations indicated a general resistance to new processes and technologies among some older or more experienced workers. This resistance often stemmed from a preference for traditional methods perceived as more reliable or easier to manage, despite the potential benefits of new technologies or processes aimed at efficiency and sustainability.

Communication and understanding barriers: While not directly noted before, communication barriers were evident, particularly between different levels of the workforce. There was a noticeable disconnect in how information was disseminated from management to the construction workers. This often resulted in misinterpretations or delays in receiving critical information. Furthermore, the contractor expresses a disagreement of how progress reporting is done. "*If I were the director of a main contractor, I would have asked all construction managers to go on a tour of the construction every morning before the morning meeting.*" (Appendix 1). This could be a resistance for the program of planning meetings or other initiatives where the two professions meet.

Inadequate training: The effectiveness of new tools and methodologies was often undercut by insufficient training. Workers were sometimes expected to adopt new technologies without adequate instruction or time to adjust, leading to inefficiencies.

Cultural and organizational silos: The observations also highlighted a cultural divide, as mentioned, between the planners educated through higher education systems and the construction worker trained in vocational settings. This educational and cultural silo effect led to differing priorities and approaches to work, which sometimes resulted in conflicting objectives and misunderstandings.

Lack of accountability: There were instances where lack of clear accountability led to delays and non-compliance with set procedures. This anti-program is also found in the expert interviews, where it is described how contracts reduce accountability.

Environmental constraints: Practical challenges related to weather conditions and other environmental factors were also observed. These issues were often not adequately anticipated in the planning phases, leading to reactive rather than proactive management of such challenges on site.

These additional anti-programs highlight the complexities and challenges of implementing planned actions within a dynamic construction environment. They manifest the need for adaptable and resilient planning processes that consider and actively order the human actors of the construction site.

7.3. A QUALIFIED MATCHING-GAME OF PROGRAMS

The notion of Latour's programs of action (1992) – when brought into design of devices and the realm of technology – can be used to connect and visualize the processes of the programs and anti-programs. This visualization creates a storytelling and a deeper understanding of why some initiatives for construction site planning, is not adhering. The connections are between actions (programs) and the counter reactions (anti-programs). This process, as illustrated in the key example (Chapter 7), can be relatively straightforward when all programs originate from a single actor. However, in the context of construction site planning, the situation is much more complex. Implementing changes in construction site planning cannot be attributed to a single actor. Instead, the concept of construction site planning emerges from the contributions of multiple actors within the sector, predominantly from the planning phase (Appendix 1). Furthermore, the involved actors do not have the same intentions as to why they are routing for the implementation of planning processes. With these complexities in mind, it is possible to connect programs and anti-programs based on a thoroughly understanding of the field. It is still notable that these connections between programs and anti-programs are based on assessment and qualified interpretation of the field. As the empiric material for this thesis is based on partial and situational knowledge, observations made cannot obtain such details for other construction projects. Thereby, the visualization is not a full descriptive representation of the real world.

On Figure 3, the programs and anti-programs found in the field of construction site planning is visualized. The programs and anti-program's titles correspond with previous more detailed descriptions found in chapter 8.2.1 and 8.2.2. The colors represent the general origin of the programs and anti-programs. The white programs and anti-programs are described by professions/actors in the planning phase and the green anti-programs are observed on-site and described by the professions/actors in the execution phase. To differentiate between programs and anti-programs, the anti-programs are written in italic text.

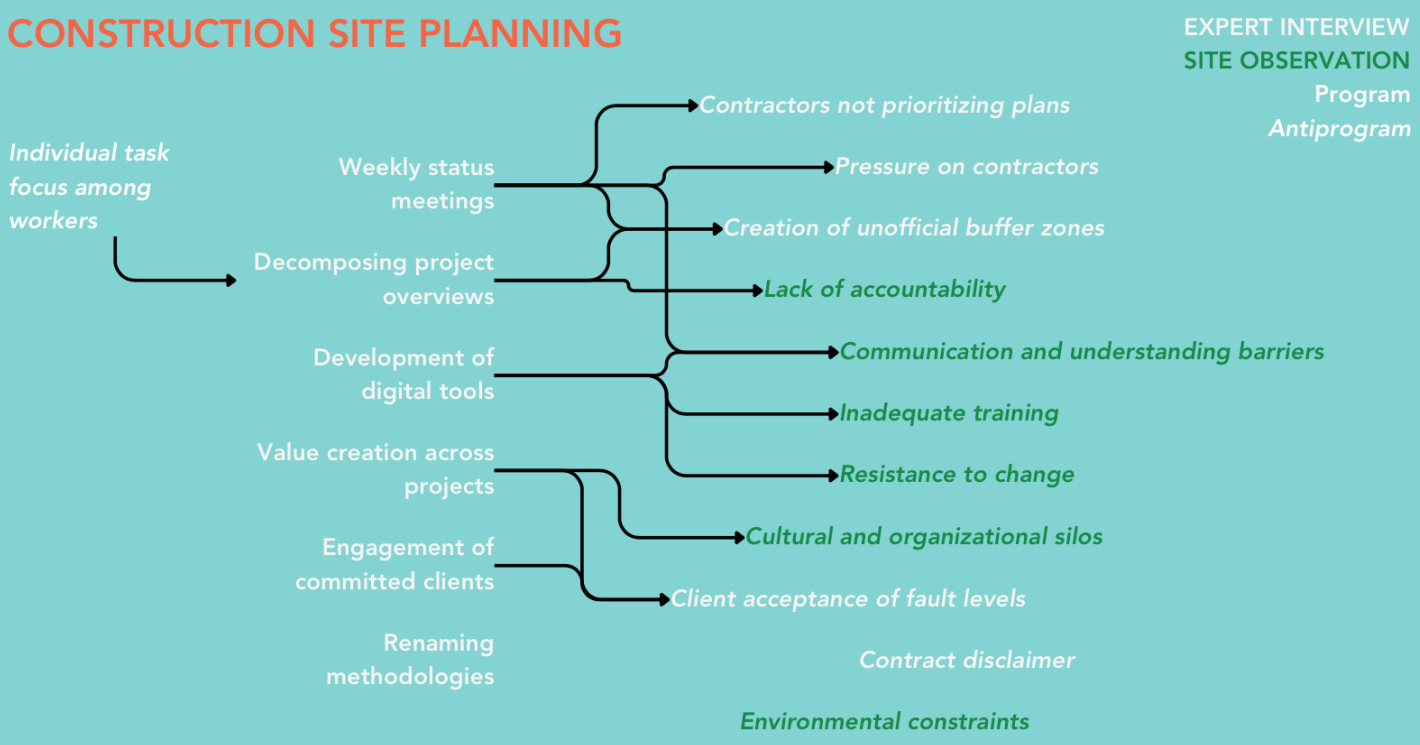

Figure 3: A visualization of programs and anti-programs on the construction site in relation to planning.

From Figure 3, we can begin to understand the dynamics of the construction site. Most notably is that some anti-programs are not being discussed and no programs are trying to accommodate them. An example is environmental constraints, that are preventing construction workers to work as planned due to weather conditions (Appendix 3). Furthermore, the program of renaming methodologies to avoid adoption resistance has no associated anti-programs. The answer to why that is, may be found in the study by Grytnes et al. (2018), showing that most construction workers, hence working on a construction site planned on the framework of Lean Construction, are not familiar with of the theory.

7.4. SUSTAINABILITY AS AN ON-SITE INITIATIVE

As the subject of construction site planning in the analysis, did not include the assessment of sustainability in on site planning, we use the understanding of programs and antiprograms to see where there is potential for actions towards a sustainable construction site planning. The following sustainable initiatives are based on the definition of sustainability of construction site planning; unnecessary material and immaterial processes that causes waste. Several key factors and strategies can be identified through programs and anti-programs to enhance sustainability and reconfigure the network of planning tools, which will be elaborated for in the next design chapter. By understanding and addressing the anti-programs while promoting the programs that support sustainability, construction site planning can evolve to become more sustainable. Furthermore, it is also relevant to understand which programs and/or anti-programs are hindering sustainable initiatives. The following descriptions are not exhaustive, but rather identified as key factors on construction site planning.

7.4.1. ANTI-PROGRAMS HINDERING SUSTAINABILITY

Several anti-programs indirectly hinder the implementation of sustainable practices but are not interpreted to be purposely against sustainability. Budgets often prioritize immediate cost savings over long-term sustainability benefits. Day to day sense of urgency is prioritized, neglecting overall project efficiency. This cause eruptions in time management, leading to materials destroyed by the weather, incorrectly order of work done by professionals, leading to rework (Love & Smith, 2019). Furthermore, this causes frustration among construction workers as well as waste of material (Gottlieb, 2023). There is often insufficient knowledge and training in sustainable practices and/or technologies accommodating resource management among construction professionals. This lack of expertise is compounded by resistance from actors who are accustomed to traditional methods. SME construction companies may lack access or knowledge on complex planning tools for construction site planning (ConTech Lab, 2023), hence when getting hired for a larger construction project, they have no prior experience or relation to the planning process and tools.

At last new sustainable technologies may face compatibility issues with existing systems and practices, therefore it is important – especially in a rigid sector – that new tools and method are somewhat compliant with existing systems. By addressing these anti-programs and leveraging the programs that promote sustainability, construction site planning can be significantly improved.

Francis and Thomas (2019) highlight the importance of integrating Lean Construction principles with sustainability to overcome these challenges. Lean practices, such as eliminating waste and optimizing processes, align well with sustainability goals by improving resource efficiency and reducing environmental impact. However, one of the primary challenges in this integration is the traditional focus on economic benefits in Lean Construction. To truly achieve sustainability, the scope of Lean practices must be expanded to include environmental and social dimensions: a holistic approach.

7.4.2. POTENTIALS FOR SUSTAINABLE IMPLEMENTATIONS

For construction workers we argue that, understanding the resource consequences of their actions and how these affect subsequent tasks in the construction process, are crucial for successful planning. However, the analysis shows that effective communication about these interconnections is often lacking. Workers tend to focus on their immediate tasks, operating within isolated silos without considering the broader impact of their actions. Currently, workers are exposed only to their own work. If these silos had transparent walls, it could arguably help workers see beyond their immediate duties and understand the effects of their work on the overall project. This visibility could foster a culture of sustainability, leading to more informed decisions that minimize waste and enhance efficiency.

Incorporating site conditions into construction planning tools can significantly reduce holistic waste. By anticipating weather conditions, project managers can schedule activities that are weather-sensitive, such as concrete pouring or material deliveries, at optimal times. This foresight helps avoid rework caused by adverse weather, conserving materials and resources. Additionally, weather predictions can guide the protection and storage of materials on-site, preventing damage. This strategic planning enhances the overall efficiency of the construction process and aligns with sustainability goals by both minimizing holistic waste and compliance with the Danish National Strategy for Sustainable Construction (Indenrigs- og Boligministeriet, 2021).

Visualizing the value chain of planning and execution on construction sites emphasizes the importance of sustainable practices. It shows how small decisions impact overall resource consumption and highlights deficiencies in contracts and project structures. This visualization aligns all actors with sustainability goals, fostering a culture of continuous improvement and optimizing the construction process for minimal environmental impact and maximum resource efficiency.

In conclusion, the reason for planning devices in the sector is to control and order an otherwise chaotic construction process by establishing structures that can be navigated by the actors. There have been many programs to establish this order and regulate clear boundaries for misunderstandings to diminish. Implementing sustainability in construction site planning is key due to the great potential of creating better workplaces and contend workers, but it involves understanding the interconnected nature of construction tasks, incorporating weather predictions, and visualizing the value chain that can lead to a joint project-oriented effort in achieving these goals. Overall, the notion and visibility of holistic waste is key to unfold the sustainability discourse in the sector, which is obtained by focusing on these areas when designing suggestions for planning tools that reconfigure the network of the construction site.

7.5. ANALYTICAL FINDINGS

The field of construction site planning and sustainability is complex and multifaceted, involving a broad range of topics and considerations. These topics are explored throughout the analysis to produce practical and useful findings, which will be utilized in the following design chapter to create design suggestions for planning professionals to develop effective planning devices. The research question, "How does the utilization of insights from programs define a space for design optimization of a construction site planning device?" has been explored through the lens of ANT and Latour’s framework of programs of action.

The analysis within construction site planning reveals a complex network of professionals and smaller enterprises, each with individual and divergent interests. Understanding these relationships fully requires considering both human and non-human actors, such as planning devices. This complexity suggests that sustainable construction site planning must integrate diverse actors and technologies to create cohesive and effective construction site planning.

Industry programs highlight how regulatory framing programs are established, contributing to a rigid field for the on-site programs to operate within. Furthermore, the chapter emphasizes the importance of executing planned actions with high quality and engaging all relevant actors. Standardization and digitization can increase efficiency and precision but require flexibility and comprehensive support to be effective. Significant gaps and challenges, such as environmental constraints and lack of familiarity with theoretical frameworks, like Lean Construction, were identified. These findings suggest that sustainable planning must be adaptable and resilient, addressing both the strengths and limitations of current programs.

The on-site programs highlight the intricate interplay between theoretical planning and practical application. Joint project-orientation, digital tool adoption, amongst others are critical for enhancing sustainability. These programs strive to bring order to the chaotic construction process by establishing frameworks for sustainable planning devices but is met with the anti-programs of the established traditions on the construction site. Therefore, the effectiveness of programs often depends on their ability to engage all relevant actors on the construction site and not only in the planning phase.

The potential for sustainability in construction site planning lies in establishing programs that control and order the chaotic construction process. Key areas include understanding interconnected construction tasks, incorporating weather predictions, and visualizing the value chain for a joint project-oriented effort. The notion of holistic waste, defined as unnecessary material and immaterial processes that cause waste, is central to this approach. By focusing on holistic waste, we aim to advance sustainability discourse and reconfigure planning tools to foster a sustainable construction environment.

In conclusion, the research question is addressed through several key findings. Sustainability in construction site planning extends beyond CO_2-emissions to include holistic waste management, efficient resource- and time use, and creating better workplaces. Utilizing insights from industry- and on-site programs reveals the necessity of bridging theoretical planning with practical execution. Sustainable construction site planning devices must be adaptable, resilient, and capable of handling dynamic environments. By focusing on these aspects, the research provides actionable insights for practical design suggestions to aid professionals in the construction sector, contributing to a sustainable construction process.

8. DESIGN SUGGESTIONS FOR PLANNING DEVICES

In the following chapter, we explore how the findings of programs of action from the analysis can be translated into suggested designs for construction site planning devices. The focal point for designing is the dissonance between the theoretical and practical execution of the planning which mobilize the right actors into the planning process. This addresses the research sub-question three: How can a construction site planning device be designed to foster sustainable actions on site? The goal for the design process is to create design suggestions that planners can use in their development of construction site planning devices. These design changes must reconfigure the network towards involvement for a sustainable construction site planning. The design method is based on a morphological chart, described in chapter, with the approach of emphasizing collaborative design processes to enhance the useability and sustainability of the proposed planning devices. The sector is not in need of yet another non-domesticated planning device but rather an adoption and mobilization of the relevant actors in existing planning devices. This approach calls for further involvement and generalized symmetry (Latour, 1992); hence the focal point of the framework will be the non-human actor – the planning device – and how it can exist with more agency in the network.

8.1.1. TRANSLATION INTO DESIGN FUNCTIONS

To accommodate the challenging process of translating findings from the programs of actions into design functions, a morphological chart was employed to generate solutions for reconstructing or redesigning the socio-technical network of construction site planning devices. These design functions were derived from a thorough translation process, which involved categorizing and coding the descriptions of programs of action. This translation process ensures that the design functions address the most critical aspects of construction site planning. In the design process we have been translating the anti- programs into functions in a morphological chart. We want to explore how networks and functions can be designed to reinforce the symmetry of actors resulting in creating order in the chaotic field of construction to become sustainable. This allows for a more holistic approach to addressing the complexities of construction site planning. The functions (Figure 4) to design for are: display values for contractors, minimize holistic waste, support self-organized zones and viewing tasks and associated impacts.

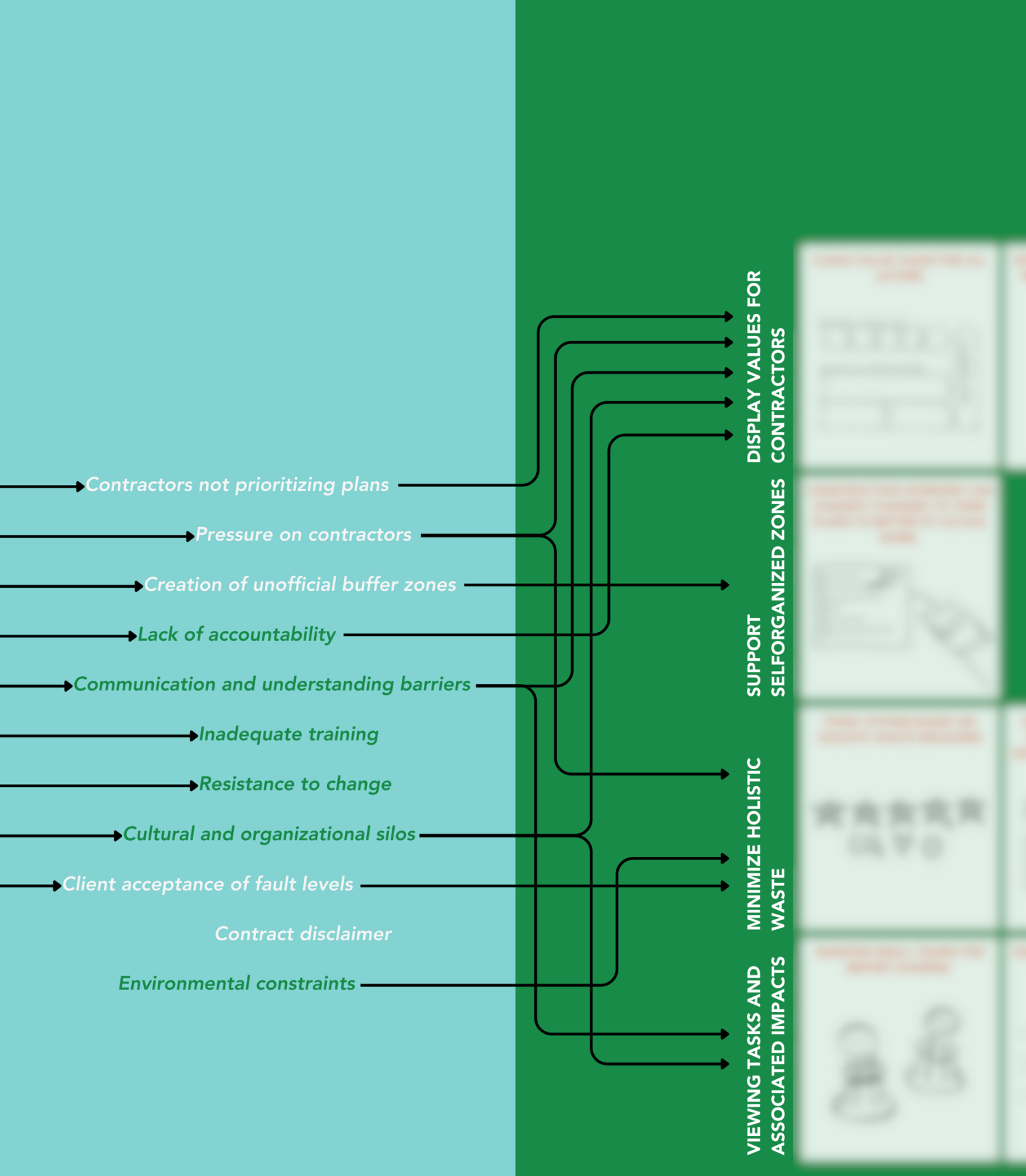

Figure 4: The process from programs of action (blue section) to design functions (green section).

Displaying values for the contractors is a design function that focusses on the lack of ownership in the planning process of construction sites. Evenly has the discrepancy between the practical and theoretical planning been evident in the cultural and organizational silos. By applying this design function, the problematization of crossing the boundary of theoretical and practical dissonance is addressed. The contractors must find value planning process merging into a more practical context.

Unofficial buffer zones are the response of a theoretical and practical dissonance, that create chaos between the theoretical framework and the physical zones on the construction site. This needs to be accommodated in a reconfiguration of the socio-technical network. When designing for functions to support and order the self-organized zones into the planning processes, the acceptance and incorporation of physical buffer zones can create order on site for the planners.

Focused on reducing holistic waste, this design function aims to minimize unnecessary material and immaterial processes that cause waste. By addressing these inefficiencies, the design helps in managing environmental constraints and improving overall project quality.

At last, we argue that viewing tasks and associated impacts for the construction workers is a design function that addresses one of the main reasons for the unsatisfactory of construction workers and for many delays in the construction process. The importance of accommodating communication and understanding barriers can create clear impact visualizations minimizing mistrust.

Creating the subsolutions for the morphological chart must be seen as a preliminary step towards a co-design session with relevant actors in construction site planning, where the chart is to be developed further. The project specific morphological chart framework of subsolutions can be seen in Figure 5. We suggest involving actors in the process of creating and brainstorming subsolutions with a workshop based upon the presented morphological chart. The design suggestions address planning professionals in the process of further develop or changing the design for construction site devices. The planning professional must mobilize and engage at least contractors and construction workers due to their key role in the practical application of construction site planning.

In the following chapter we will elaborate and describe the subsolutions from respective design functions.

MORPHOLOGY CHART – CONSTRUCTION SITE PLANING DESIGN SUGGESTION

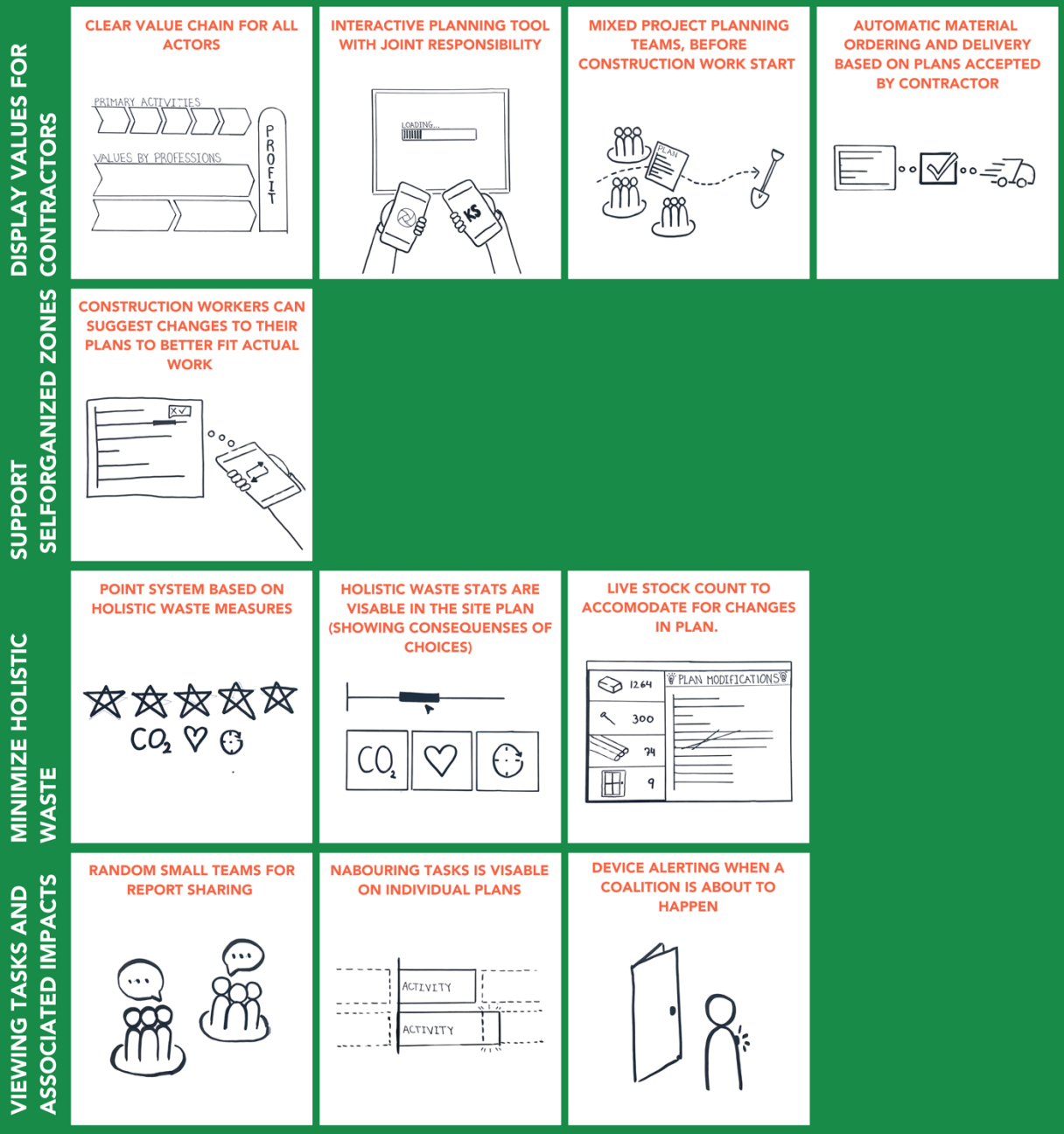

Figure 5: Morphological chart showing design suggestions for future sustainable construction site planning tools.

8.1.2. DISPLAY VALUES FOR CONTRACTORS

Clear value chain for all actors: Visual representation of primary activities and values sorted by profession to enhance common ground and understanding through the value chain of construction site process e.g. construction site planning. We have seen in the analyses that a common value helps a project in the right direction of collaboration, hence the focus on making the value chain or progress visual for the individuals.

Interactive planning tool with joint responsibility: The construction site plan must be formed throughout the construction process, where construction workers co-design the plan and thereby responsible and feel ownership for parts of the planning. The ownership is key for involvement of the actors in the process and creating plans that have a practical effect. To foster useability and simplicity the digital devices must be known and already used by the construction workers. This subsolution will reconfigure the exiting planning process which is currently theoretically bounded outside of the on-site network.

Mixed project planning teams before construction work start: Encourages early collaboration among diverse teams to ensure comprehensive planning. It is important here, that these planning teams are formed in the early design phases to create common values. It is evident that this will be difficult to employ due to change of the current planning processes and which actors are invited to the different phases. The multiplicity of actors involved will have an impact on the entire planning phase configuration, hence the adoption of on-site actors.

Automatic material ordering and delivery based on plans accepted by contractor: Streamlines the procurement process by automating material orders as per the contractor-approved plans. The automatic material ordering is saving time which then could be allocated elsewhere. Furthermore, would the ordered material align better with planed use, minimizing material waste. It is important that these orders are accepted in a notification alert by the contractor to ensure no mistakes.

8.1.3. SUPPORT SELF-ORGANIZED ZONES

Construction workers can suggest changes to their plans to better fit actual work: Allows workers to propose adjustments to plans based on real-time conditions and practical insights. This allows for more ownership of the process and plans that are more likely to follow the reality on the construction site. The analyses points to that gap between the theoretical planning and the practical execution of plans which can be accommodated by opening for construction workers to interact with the planning device. When implementing practical insights into the theoretical framework, it will create bigger complexity for the planning responsible, due more data of real-time operations.

8.1.4. MINIMIZE HOLISTIC WASTE

Point-system based on holistic waste measures: We stated in the analyses that holistic waste needs to be made visual and therefore also measurable. By implementing this kind of scoring system, sustainability can be fostered by competition across projects. A certification system in this new paradigm might even be adopted into the domesticated certification tools to accommodate new regulations in the sector.

Holistic waste stats visible in the site plan (showing consequences of choices): Display of holistic waste statistics and data to inform decisions and highlight the impact of actions. This design is based on the idea of making waste visible; making planners and contractors more inclined to act on culprits. This reconfiguration will appear in a conflict with the anti-program “lack of accountability”, hence the visibility of responsibility.

Live stock count to accommodate for changes in plan: A live inventory system to manage resources efficiently and adapt to changes in the construction plan. This would foster a “work-with-what-we-have” mindset, minimizing un-planned construction stops. It could potentially disrupt with planned deliveries and material uses. Similar concepts have been integrated by “Just in Time”-delivery[5].

[5] leanconstruction.org/lean-topics/just-in-time

8.1.5. VIEWING TASKS AND ASSOCIATED IMPACTS

Random small teams for report sharing: The silo narrative is evident in the construction sector, but by assembling smaller randomly assigned teams to share progress and insights this can be accommodated. The teams will be multidisciplinary to promote transparency and accountability towards the other actors in the construction processes. It will definitely be a new working process that might have difficulties of implementation due to the rigid workflows in the sector, but it has a possibility to create well-functioning teams.

Neighboring tasks visible on individual plans: A feature that shows related tasks from other construction workers on individual work plans to enhance coordination and reduce conflicts. In this way the construction worker, is more aware of the combination of tasks in the construction process.

Device alerting when a collision is about to happen: By implementing digital zones with the planning device and a notification system to alert workers of potential task collisions that could prevent rework and delays. It will require extensive construction site data which contractor or client might be inclined to invest in. This illustrates the importance of a clear value chain for construction site planning.

8.2. DESIGN SUMMARY AND FURTHER WORK

The morphological chart organizes design ideas to enhance the sustainability of construction site planning, embedding sustainability at every stage, reducing waste, and improving resource management. It fosters continuous improvement and accountability among all actors. Practical solutions include interactive planning tools, automatic material ordering, and real-time waste statistics. The chart comprehensively answers the research question on designing construction site planning devices to foster on-site sustainability, providing specific, actionable strategies for further development into existing planning devices and networks. The morphological chart is suggested to be used as a foundation for a co-design workshop with relevant actors in construction site planning. This workshop will further develop the chart by creating and brainstorming subsolutions. The primary users of the morphological chart are planning professionals who are involved in developing or modifying the design of construction site planning devices. It is crucial to involve contractors and construction workers in the workshop, as their practical experience and key roles in the application of construction site planning are essential for effective and sustainable design outcomes.

9. REFLECTION

In the following chapter we will present reflections and discussions of three dimensions of this thesis. These are with the purpose of reflecting upon the relevance of suggested design outcome and how different approaches would have formed different outcomes. Furthermore, it is reflected, how the theory of ANT and Latour's work on programs of action (1992), have formed the analysis and the ontological and epistemological bases for research. At last, an alternative perspective on managing construction site planning is discussed with the intent of fostering better planning and therefore a sustainable construction site.

9.1. ANALYTICAL FINDINGS AND DESIGN REFLECTION

In this chapter we will discuss and reflect upon the findings of the analysis and the design suggestions for construction site planning devices. This will touch on objects of research that is not further investigated in the thesis, to understand how research-based choices has formed the final design.

The design suggestions in this thesis are intended for general implementation across the Danish construction sector rather than tailored to a specific network. Our research revealed that most planning devices and methods used on construction sites follow similar principles, although some differences exist. Thus, the goal is to create a design outcome that can be integrated into these existing planning devices, ensuring both relevance and feasibility. For sustainable changes to be effective in this relation, they need to be broad enough to apply to various construction projects. At the same time, the design suggestions must be specific enough to address the unique challenges and obstacles – anti-programs – present on each site. This balance will ensure that the proposed designs are both practical and adaptable to the diverse conditions encountered on the construction site. Drawing on desk research, expert interviews and on-site observation, this duality is evident in the thesis final design suggestions.

Another approach to sustainable changes of construction site planning, would be a case study. The case study would be able to focus on the specifics of a construction site and from there suggest design optimization. The relevance for the construction sector would lie in inspiration and learnings from that one specific site. Due to the complex setup involving various professions on a given site, as well as the size of the site and construction project, it is challenging to provide a broad perspective. This complexity has been highlighted in previous research, making it difficult to generalize findings (Yang, et al., 2021).

In this thesis, we examined how planning can be made more accessible and useful for construction workers and contractors. To achieve this, we developed design suggestions that can be integrated into planning devices to encourage their usage by these professionals. During our investigation and analysis, we also identified a different perspective on the issue of inefficient planning. During the site observation a construction worker was commenting on the planning processes, stating that if the engineers and architects could just start by finishing the project plans, constructing it, would be a whole lot easier (Appendix 3). This points to another aspect of the construction site planning, that is not further investigated in this thesis and questions whether the focus should be on the execution of the actual plans. We argue, that while this is also an important subject – and should be considered for further research – there is a need for managing the chaos of actors and interest on the construction site. If we do not have methods and tools to manage the construction site, it is very difficult to implement any ideas on how construction should develop and become more sustainable. Even if the project plans for the construction site is 100% completed and correctly executed, there is still a need for creating order between the many actors and their work.

These thoughts also lead into the discussion of how to manage the flexibility that we see a need for in the construction site planning. Since construction site plans can never be 100% complete, it is essential to allow flexibility for changes. Furthermore, weather conditions also affect the stability of the planning. Creating flexible planning is quite an oxymoron, where planning require stability and flexibility is the opposite. To account for some flexibility, design suggestions for enabling construction workers to suggest changes to accommodate for practicality is a way to manage the on-site planning. Another way to account for this complex to-sidedness is presented in the last chapter of the reflection (Chapter 9) where fundamental ground for planning is questioned.

9.2. REFLECTION ON THORETICAL APPROACH

The relevance of using the theory of ANT, its insights, and the challenges encountered will be discussed in relation to the research question: How can a construction site planning device be designed to foster sustainable actions on-site? Using the theory to investigate the phenomena of insufficient construction site planning, has proven to highlight some interesting and practical solution spaces. The theory has also had some limitations, framing the approach and object of investigation. These aspects will be discussed in the following chapter.

The application of ANT has influenced our design approach by emphasizing the need to consider both the technical functionalities of planning tools and the social dynamics they facilitate (described in chapter 5). This perspective has encouraged the development of tools that are not only technically robust but also socially inclusive and adaptive. For example, tools that manage the complexities enabled by digitization while accommodating the diverse work approaches of different professions on-site. This specific characteristic of ANT, where knowledge is not something to find, but rather a social construction of both human and non-human actors' relations, is fitting in the context of investigating construction site planning. In a heavy technical and engineering-based field of construction, this lens of symmetry between human and non-human as well as social and technical, provides some new aspects to the field research.

This theory is also particularly relevant in the field of construction site planning, as it is a network where many non-human actors play a crucial role on both the construction work, but also in the planning processes. The large and complex construction sites make it impossible to complete without planning tools. At the same time, it is a field where the human actors, is working within a traditional and rigid cultural environment, that is not keen to changes. The dynamic creates complex many facetted anti-programs, when looking to implementing better planning and sustainable changes.

Despite its usefulness, ANT also presents constraints. One significant difficulty is that many ordering mechanisms within construction site planning remain invisible when viewed through the lens of ANT. Understanding hidden elements, like cultural underpinnings and reasons behind anti-programs, requires supplementary methods to capture the construction site's full complexity. Investigating anti-programs through thick descriptions will uncover the culture and norms, contributing to the specificity of this thesis's findings.

9.3. REFLECTIONS ON SUSTAINABILITY

Time-based planning is in this chapter discussed with the goal of assessing the best planning approach for sustainable construction site planning. This critique of the current approach is relevant to the investigation of how to implement sustainable planning on construction sites, as it forms the foundation of existing planning methods. However, this discussion of the time aspect is an abstract topic. For this reason, we consider the topic important in the discussion of a sustainable transition, but not directly implementable for the sector.

A plan is successful, when it is executed within the time frame of what is planned for. If one plans to build a wall over the course of two days, the plan is considered successful if it is completed within this timeframe. If not, the plan has failed. In this line of thought it would be wise to plan based on a stable and predictable variable if the goal of the plan is to be successfully completed. On the construction site most, unpredictable activities significantly impact the time-based planning. As this study aims to investigate how construction site planning can be improved, highlighting the unreliability of time as a sole planning factor is relevant for discussion.

Time amongst construction workers is most critical in the contractual structure of piecework. Here, a worker's salary depends entirely on how quickly a job is completed. This extreme focus on time creates unsafe situations where not only material errors occur, but also more accidents happen. For piecework employees, the risk of serious workplace accidents is 1.7 times higher than for colleagues on hourly wages (Troelsen, 2017). From this view, the heavy focus on time is creating errors in other aspects such as health and material waste which is acting as barrier for holistic waste management.

When planning is based on time, individuals on the construction site is provided a plan with activities they need to complete within a specific time frame. This creates a setting where the construction workers are focused on doing their individual task, rather than prioritizing the construction project. If there were no complications or task overlap, this would in theory work, but as Veis from Exigo (Appendix 1) described it is not the case. When unresolved task overlaps occur and different professions intersect on the construction site, prioritizing individual tasks over the overall construction process leads to inefficiencies and thereby contributing to the formation of silos. In the context of sustainable construction site planning, this would be a problem as holistic project resources must be prioritized.

Another aspect hindering holistic waste reduction in construction site planning is the sector's focus on economic profit of individual professions, aligned with time-based planning. If sustainability were prioritized, the focus on economic profit would act as a barrier. When a building's value is based solely on siloed economic profits, other values are overlooked. Economical profit being the one and only value to be prioritized in the construction sector, is something that we often hear (Appendix 1). Whether or not this is done successfully could be questioned. Most Danish companies within the construction sector make less than 4% profit (Frommelt, 2023). If economy is so important, why is construction work not more profitable? Prioritizing economic value overlooks minimizing resource use and workers' health. Overlaps, such as material waste, also cause economic loss for contractors. Despite this, such losses are often accepted in the construction sector: "*It should not be a double-digit profit. If only it is between 5 and 10 percent, then they are happy. And you can realize that by doing half-bad work.*" (Appendix 1). Because of this, one could argue that the heavy focus on economic values is an excuse for a deeper cultural persistency in traditions and apprenticeship.

When looking at a sustainable perspective, unnecessary material and immaterial processes that causes waste must be what we seek to minimize. This raises the question: Is it possible to plan construction projects based on resource utilization, and is such an approach feasible for implementation within the construction sector? Emphasizing resource-based planning would have several advantages, particularly in terms of sustainability. The resource-based planning prioritizes the efficient use of materials and human resources, which reduces holistic waste. This approach could align with global sustainability goals (United Nations Environment Programme, 2021) and can significantly enhance the environmental performance of construction projects. Focusing on resource management can improve worker health and safety by reducing the pressure of strict deadlines, thus lowering accident rates. Though cost efficiency may seem overlooked, this perspective sees it differently. Initial investments in efficient material and labor use can lead to substantial long-term savings and minimize financial risks from delays and waste.

The discussion and critique of time-based planning are quite abstract, requiring critical thinking that extends beyond the established systems within our society. Such approaches are often missed, but not less important. In the goal of implementing sustainable initiatives leading to a transition, it is often these underlying systems that are the grounds for unsustainable practices and cultural habits. As a sustainable design engineer this handling of abstract systemic critique pared with concrete design suggestions for wicked problems, is uniquely contributing to the field of a sustainable construction site.

10. CONCLUSION

Construction site planning has been a topic of advancement for many years, although not in the context of contributing to sustainability. Hence, this study was initiated to explore that connection through the research question, how can construction site planning contribute to a sustainable construction process?

Initiatives and definitions of sustainability in the construction sector uses the technical measuring method of CO_2-emissions, which is the recent discourse. That definition is not comprehensive for this project when implementing sustainability in the planning process. By defining how a planning device can contribute to a sustainable construction process we have drawn upon literature on waste definitions and the existing planning devices' contribution to minimizing waste. That led to the nuanced definition of holistic waste: unnecessary material and immaterial processes that causes waste. By holistic waste we also define how it can be sustainable to plan more effectively on-site to minimize conflicts and coalitions.

Throughout this project we have drawn on experts in the construction sector with widespread expertise in the planning phase of construction. The experts have all pointed to discrepancies in the theoretical planning process and the practical execution of the construction site plan. The existing planning devices are intended to make the process leaner but do not mobilize actors outside the theoretical planning. Therefore, the field is not lacking the tools and devices for implementing project management, but it lacks values that are shared by the actors involved in the construction process. We argue that there is no need for yet another device but rather a reconfiguration of the relations between actors.

Individual and divergent interests of the actors on the construction site can be said to reflect the rigid constraints imposed by regulations. These interplays on the construction site are unfolded using the theory of ANT and Latour (1992), exploring the dynamics and design vision between construction site planning and on-site activities. Hence a reconfiguration of the network is crucial for both the order on-site and to reach sustainable processes created from a perspective of minimizing holistic waste.

Using the morphological chart method, the design systematically explores practical and adaptable solutions to reconfigure the socio-technical network of the actors on the construction site. To further refine these design suggestions, the chart should be used in co-design workshops with planning

professionals. This collaborative approach ensures practical and effective sustainable design outcomes, enhancing construction site management**.**

The thesis also reflects on the socio-technical aspects of sustainable research of design engineering, recognizing that sustainable construction site planning requires not only technical solutions but also social considerations, highlighting the complexity of the network. It emphasizes the importance of engaging a diversity of actors, understanding their interests, and fostering collaboration to achieve sustainable outcomes. By focusing on holistic waste, the thesis advances the discourse on sustainability in construction, providing a more comprehensive understanding of its environmental, social, and economic impacts. The research addresses the real-world complexities of sustainability in construction site planning, contributing to the field of sustainable design engineering.

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