Assessing disruption-coping activities in district heating construction projects to enhance the reliability of project organisations

Wilco W. Jonker[1]

31 January 2023

Abstract: The energy transition stimulates the shift towards sustainable heating systems. District heating networks are one of the main infrastructures that can enable this transition. The construction operations for these networks involve placing large rigid pipelines into a crowded urban subsurface. The integration of these networks poses unique coordination challenges and necessitates the acquisition of new technological expertise in order to deploy these networks in an efficient manner. This context offers a unique perspective on processes that strive for reliability within forms of emerging project organisations. Therefore, interviews and non-participatory observations are conducted at the district heating department of a utility contractor to gain insight into their activities for coping with disruptions. The adapted mindful organising framework identifies the use of seven reliability-enhancing and five reliability-reducing activity types by the project team. These findings indicate that the team utilises their implicit knowledge and improvisational actions to cope with disruptions. However, these implicit organisational practices impede project teams from scaling up the implementation of district heating networks. Therefore, a workshop session was organised that resulted in the formation of seven practical mechanisms to enhance project reliability, these mechanisms can serve as a stepping stone towards improved project efficiency.

Keywords: District heating; Utility construction; High-reliability organising; Process disruptions; Implicit knowledge.

1. Introduction

District heating (DH) projects involve the deployment of a new type of utility infrastructure to provide heat to buildings through a network of insulated pipes (Boesten et al., 2019; Lund et al., 2014; Werner, 2017). A number of studies have shown that these networks can be widely implemented in sustainable energy systems (Boesten et al., 2019; Connolly et al., 2014; Fahl & Dobbins, 2017; Lake et al., 2017; Lund et al., 2010; Lund et al., 2014; Persson & Werner, 2011; Werner, 2013). DH networks are therefore seen as one of the main utility infrastructures for the energy transition. The expectation is that the need for DH networks will increase enormously because a transition to sustainable heating systems will be made in the coming years (European Commission, 2022).

According to the association of utility network operators (Netbeheer Nederland, 2017), it is necessary to massively scale up the implementation of DH networks in the coming years to achieve the goals of the Dutch government to phase out natural gas for heating (Rijksoverheid, 2019). The large-scale implementation of this network is expected to lead to an increase in employment due to the labour-intensive nature of the value chains of sustainable technologies (Ram et al., 2022). The transition to renewable energy sources in the heating sector also has the potential to create a significant number of jobs, as shown by Connolly et al. (2012) for the transition of the European heating sector. The construction of DH networks requires the collaboration of skilled engineering and construction professionals. However, a limited number of project teams are currently capable of implementing these types of networks.

[1]*Student, W.W. Jonker, Department of Construction Management and Engineering, Faculty of Engineering Technology, University of Twente, PO Box 217, 7500AE, Enschede, the Netherlands.*

Examination Committee:
Daily Supervisor, dr. ir. L.L. olde Scholtenhuis, Department of Construction Management and Engineering, Faculty of Engineering Technology, University of Twente.

Supervisor, prof. dr. ir. A.G. Dorée, Department of Construction Management and Engineering, Faculty of Engineering Technology, University of Twente.

Note. *This paper is part of the Master Thesis assignment for the programme Construction Management and Engineering. Colloquium: 31 January 2023.*

Training new professionals can be challenging due to the complexity of the networks and inherent risks during construction. The implementation of this new type of asset often takes place in existing districts that are densely populated (Maria Jebamalai et al., 2019; Paiho & Saastamoinen, 2018; Persson & Werner, 2011). The working environments of the construction crews are often complex and uncertain as it can be affected by changes in the environment, weather conditions, stakeholder coordination, and logistics (Enya et al., 2018). The limited workspace and site layouts in urban areas also negatively affect the workflow of construction activities (Lucko et al., 2014) and the productivity of operations (Elbeltagi et al., 2004). During the construction of the pipeline route, it is common to encounter spatial constraints both above and below ground (Talebi et al., 2016; Weber et al., 2007). Above-ground constraints include buildings and civil structures, while underground constraints include, for example, foundations, tree roots, cables, and pipelines (von der Tann et al., 2018). Data from these constraints is not always correct or readily available, especially for utility data from existing cables and pipelines (Jeong et al., 2004). This makes it a challenge to fit in the large rigid pipes, which are technically complex due to their need for thermal expansion, and the requirements set for the joints that need to be insulated and leak-tight (Werner, 2013; van der Stok, 2014). Not only does this require specialised professionals who can perform these activities in the limited space that is often available, but the large-scale implementation of these networks requires new technological expertise to efficiently integrate this physical asset into the existing crowded urban subsurface (Jeong et al., 2004).

These complex and uncertain environments can lead to disruptions of processes that reduce productivity and can eventually lead to delays if not mitigated (Oommen, 2021). Process disruptions are often unexpected and unwanted events. Such hold-ups need to be solved before construction work can continue on-site. Practitioners often perform implicit activities using their expertise and skills to implement the networks. When faced with issues such as hold-ups they apply improvisational activities and make changes or adjustments to the intended design on the construction site. Solving disruptions through improvised activities on-site is a common practice. However, improvised activities are characterised by inefficient work processes that often result in cost and time overruns (Zidane et al., 2015).

To support the efficiency of DH network implementation, it is needed to minimise delays and keep the project on track in order to ensure timely and cost-effective completion. By utilising these optimised processes, it becomes possible to scale up the implementation of DH networks massively in a more efficient way. Furthermore, these processes provide a framework for training new professionals based on explicit knowledge in the field of DH construction. In order to minimise delays and enable efficiency, disruption-coping activities need to be understood.

Essentially, it is necessary to enhance reliability within projects. Therefore, this research assesses how a project team in this emerging discipline copes with process disruptions through the mindful organising lens. Based on the assessment, this study offers recommendations to enhance project reliability by proposing practical mechanisms for the types of actions that are reliability-reducing. These practical mechanisms can serve as a stepping stone towards improved project efficiency.

In the following sections, the paper is structured by introducing the mindful organising lens and describing the principles used for the assessment. Then the methodological approach used during the research is explained. Subsequently, the types of actions that the project team uses to cope with disruptions are listed. These actions are exemplified with observations and verbatim quotes. The paper ends with suggestions for practical mechanisms that can be used to enhance project reliability.

2. Theoretical Framework

Construction management activities, such as planning, coordinating, monitoring and controlling projects, are essential for the successful completion of construction activities (Winch, 2009). Deviations from pre-planned procedures should be kept to a minimum to minimise reliance on improvised activities. However, improvisational practices continue to occur (Hamzeh et al., 2018), therefore strategies need to be adapted to enhance reliability.

Organisations that function extremely reliably while operating in complex and hazardous environments are known as high-reliability organisations (La Porte, 1996). The theory of High-Reliability Organising (HRO) provides a framework for understanding how organisations can consistently operate effectively and efficiently in complex and hazardous environments. Not only do organisations that operate in hazardous industries have to deal with undesirable situations that significantly affect their performance, but to a lesser extent, this also applies to mainstream organisations. Roberts and Bea (2001) conclude that all organisations that face disruptions can learn from HRO and implement the lessons learned. Organisations in the construction industry could benefit from the HRO theory to realise projects on time and within budget. Olde Scholtenhuis and Dorée (2013) argued that it is permissible to use the HRO principles within the domain of construction management. The HRO theory can therefore be used to improve performance and avoid non-goal actions, such as hold-ups, and non-goal outcomes, such as time and cost overruns (Weick, 2011).

In the construction industry, the concepts of HRO are adopted in various cases. De Bruijne and van Eeten (2007) analysed the impact of restructuring the utility sector on performance reliability. Mitropoulos and Cupido (2009) compared the work practices of house framing crews. Olde Scholtenhuis et al. (2016) tested the value of implementing four-dimensional visualisations for utility reconstruction works. And Enya et al. (2018) reviewed HRO as a safety management strategy in construction.

These studies indicate that organisations that incorporate mindfulness practices into their daily routines are able to attain higher levels of reliability in their operations. In these studies, mindfulness is the pattern of awareness and attention in an organisation (Weick & Sutcliffe, 2007) and it focuses on improving performance reliability by anticipating and preventing the occurrence of unwanted events (Weick et al., 1999). Mindful organisations are committed to the implementation of five HRO principles. Three of these principles are aimed at anticipation. The purpose of anticipation is to identify and prevent the occurrence of disruptions, and it is an exercise in stopping the development of undesirable prospective events (Weick & Sutcliffe, 2007). The other two principles focus on containment and are based on the resilient capability and appropriate expertise to limit unwanted outcomes after disruptions have occurred (Weick & Sutcliffe, 2007). Where anticipation encourages people to think and then act, the principles of containment encourage people to act while thinking. (Weick & Sutcliffe, 2007).

The three anticipation principles are aimed at sensing and stopping the occurrence of disruptions (Weick & Sutcliffe, 2007). The first anticipatory principle *'Preoccupation with Failure'* encourages practitioners to be continuously aware of potential failures and delays, and to proactively report near failures and mistakes in order to better cope with future events. The second principle *'Reluctance to Simplify'* focuses on obtaining a complete view of ongoing operations to prevent an oversimplification of the situation. Assumptions are not simply accepted or categorised as standard, but processes are interpreted as detailed as possible. The third principle *'Sensitivity to Operations'* supports ongoing information sharing by practitioners about how operational processes and systems interact.

The two containment principles are aimed at reducing the negative impact when disruptions have occurred (Weick & Sutcliffe, 2007). The fourth principle *'Commitment to Resilience'* focuses on the ability to anticipate and quickly develop new structures for disruptions that have already occurred. Skills and expertise are used by practitioners to flexibly cope with disruptions once they emerge. The fifth principle *'Deference to Expertise'* suggests that regardless of the hierarchy the decision-making during disruptions shifts to the expert who can respond appropriately to the situation.

Weick and Sutcliffe (2007) introduced a series of audits that can be used to provide a deep and broad insight into the organisations' tendencies toward mindfulness and the capacity to organise ways to accomplish this. A more compact way to determine if practitioners in the organisation act in a manner consistent with the HRO principles is the mindfulness organising scale (Weick & Sutcliffe, 2007) and the safety organising scale (Vogus & Sutcliffe, 2007). The items shown in Table 1 were used within the study to observe mindful behaviour and classify actions into one of the five principles.

In this way, the mindful organising lens provides a pragmatic framework for this study to assess how the project team currently copes with process disruptions and which actions they take to prevent them from leading to delays. The five HRO principles of this theory are used to link observed actions to the principles of anticipation and containment.

3. Research Methodology

This ethnographic study assesses how a project team working on DH projects copes with process disruptions through the mindful organising lens. Following this assessment, the study proposes practical mechanisms to foster mindful behaviour, intending to enhance the reliability of project organisations. The methodology for this study draws on non-participatory observations of professionals and interviews to identify actions taken by the project team to cope with process disruptions. In a workshop session, practical mechanisms are developed to enhance the reliability of the project organisation.

The data for the study were collected at a specialised contractor that provides engineering and construction services for underground utility projects. The focus was on the entity of the organisation responsible for the implementation of DH networks. In this entity, the project team is responsible for performing both the engineering and construction phases, which are vertically integrated within the organisation. Including both phases in the context of the research allowed for a comprehensive understanding of how the team copes with process disruptions and how these disruptions can affect the overall timeline and success of the project. The research specifically focuses on the implementation of distribution networks in urban areas as the type of projects under study. These projects mainly concern digging trenches and laying pipes in the subsurface, but also include the above groundwork, such as installing and connecting pipes to the domestic heating systems and the heat interface unit.

3.1. Data Collection

During the study, a combination of data collection methods were used, including observations of three ongoing projects, interviews with twelve professionals in the field of DH, and a workshop session with nine interview respondents. The non-participatory observations included the observation of two projects in the engineering phase and one project that was under construction. During the observations, construction process meetings were attended, project documents were reviewed, construction sites visited, and informal dialogues were held with professionals. The analysed documents included technical drawings, specifications, material lists, schedules, and project management documents. The observations involved observing team managers, project coordinators, project engineers, site engineers, foremen, and construction crews consisting of excavation workers, welders, and pipe fitters. During these observations, notes were made about which measures and actions the project team takes to prevent the occurrence of process disruptions and minimise their impact.

Before conducting the interviews, the interview respondents completed the mindful organising audit. This audit consists of nine statements corresponding to the mindfulness organising scale as shown in Table 1. This audit does not search for statistical generalisation but was used to make a first compact inventory if the professionals in the organisation act in a manner consistent with mindful organising.

Subsequently, twelve professionals were interviewed, to gather data about their experiences, opinions, and practices. The interview respondents fulfilled the functions of engineer, coordinator, site engineer, foreman, or team manager. A semi-structured format with open-ended questions was used to conduct the interviews. This type of interview allowed for asking predetermined questions but also allowed for individually tailored follow-up questions (Leedy & Omrod, 2015) to gain clarity regarding responses. The interview questions focused on how process disruptions are currently anticipated and contained within ongoing and previously completed projects.

After assessing how the project team copes with process disruptions, a workshop session was organised with nine of the twelve interview respondents who were able to attend this session. The workshop consisted of two parts. In the first part, we discussed the set of identified types of actions used to cope with process disruption. In the second part, the participants shared their perceptions, ideas, and opinions on how to enhance the reliability-reducing types of actions through practical mechanisms to enhance the reliability of the project organisation. During this phase, the group engaged in discourse concerning the implementation and utilisation of these practical mechanisms.

3.2. Data Analysis

To assess how the project team currently copes with process disruptions, the audio-recorded interviews were processed into verbatim transcripts. These transcripts were then reviewed and validated by the participants. This process, known as a member check, served as a validation of the transcripts. The qualitative data analysis software tool 'ATLAS.ti' was used to analyse the transcripts of the interviews along with the notes from the non-participatory observations.

In this study, pattern matching was performed by relating the units of the transcripts to the HRO principles from statements such as the questions in the mindfulness audits (Weick & Sutcliffe, 2007, pp. 85-103), and the safety organising scale of Vogus and Sutcliffe (2007). The data analysis consisted of comparing the predicted pattern of mindfulness organising to the empirical pattern found in the interview transcripts and notes from the observations. To do this, individual lines of text were first grouped based on their content, and then these groups were linked to the mindfulness principles. This allowed for the differentiation of types of activities into those that are reliability-enhancing and reliability-reducing.

In this study, the types of activities associated with reliability-enhancing and reliability-reducing categories concern both actions and non-actions. The types of actions that enhance reliability are activity types that consist of actions taken pertain to a specific task or activity performed to prevent disruption or reduce its impact. These actions are based on activities that are in line with mindful behaviour. The reliability-reducing types of activities consist of both actions and non-actions. The actions taken are not in accordance with mindful behaviour and the non-actions pertain to the adoption of a reactive approach to addressing process disruptions and thus represent a lack of action. These non-actions comprise a lack of clear structures and the failure to learn from past experiences.

Table 1. Mindfulness Organising Scale adapted from Weick and Sutcliffe (2007) and Vogus and Sutcliffe (2007).

Mindfulness Organising Scale	
1.	We have a good 'map' of each person's talents and skills
2.	We talk about mistakes and why to learn from them
3.	We discuss our unique skills with each other so that we know who has relevant specialised skills and knowledge
4.	We discuss alternatives as to how to go about our normal work activities
5.	When discussing emerging problems with co-workers, we usually discuss what to look out for
6.	When attempting to resolve a problem, we take advantage of the unique skills of our colleagues
7.	We spend time identifying activities we do not want to go wrong
8.	When errors happen, we discuss how we could have prevented them
9.	When a crisis occurs, we rapidly pool our collective expertise to attempt to resolve it

4. Results

Twelve types of activities are identified and linked to the HRO principles within the project environment of the project team. Of these twelve, the project team uses seven reliability-enhancing, and five reliability-reducing types of activities. Of the seven actions that are reliability-enhancing, four are related to principles of anticipation and three are related to principles of containment. Table 2 provides an overview of the seven identified types of actions that enhance the reliability of the project team. Table 3 provides an overview of the five identified types of actions and non-actions that reduce the reliability of the project team. The five reliability-reducing activity types were perceived as inconsistent with the HRO principles and indicated the presence of behaviours that are opposite to those associated with mindfulness. The twelve types of activities are described in greater detail in the following sections of the text. This includes the provision of examples and verbatim quotes to exemplify the identified types of activities.

4.1. Types of actions that enhance reliability

4.1.1. Conducting preparatory research and taking actions based on expertise to prevent disruptions from occurring

The project team is aware of the complexity of the networks and inherent risks during construction and therefore, they identify possible constraints at the beginning of a project in order to take necessary precautions. To do so, an engineer and foreman visit the site before starting the design process. During this site visit above-ground constraints that may affect the design and construction of the network are assessed. This involves identifying the locations of buildings, roads, and other infrastructure that influence the routing of the pipeline. The team also determines the availability of workspace for construction activities and material storage.

In addition to above-ground assessments, desk studies are performed to identify potential constraints in the subsurface that influence design choices. This may include the location of existing underground structures and infrastructure, such as cables and pipelines, as well as subsurface-related factors such as soil quality and groundwater levels. If desk studies do not provide sufficient information, additional preparatory research activities are carried out, such as utility data verification through trial pits and soil pollution determination.

During these site visits and desk studies, the project team does not follow a fixed procedure to obtain information or make decisions. Instead, they rely on their experience to guide them during these activities. The team often sees the complexity of the project location and the number of cables and pipelines in the subsurface as key factors in defining the approach to take measures to minimise process disruptions. A measure that is often taken to reduce the likelihood of disruptions occurring due to damage to cables and pipes is the use of vacuum excavation as explained by the foreman, *"The chance of damage is reduced with vacuum excavation, which is why we prefer to use it in urban areas"*.

In addition to measures to prevent damage and disruptions, alternative technical plans are also prepared in some projects to stop disruptions in a timely manner if they occur. The site engineer provided an example of a situation where the team anticipated the possibility of encountering an unexpected obstacle in the subsurface, *"The client specified a location for a valve, but during the excavation, it was discovered that the existing district heating pipe was embedded in concrete. As a result, the valve could not be installed at that location, and breaking up the concrete was not an option"*. However, the team had prepared design options for an alternative location, which proved to be useful in this situation.

In the case of complex inner-city areas, the project team does not only prepare for alternative locations but also prepares for the possibility of rerouting the network in the event that the network could not be implemented due to an unexpected obstacle. The senior engineer discussed a complex inner-city project where the team expected disruptions in the crowded subsurface based on expertise. The engineer explained that the pre-insulated fittings cannot be made and adjusted on-site but must be delivered as prefabricated elements. To account for potential deviations from the planned design, he advised the team to add some extra fittings to the inventory, *"We have included some 11° bends to accommodate a small difference, and an additional Z-bend, one element in case we encountered something we had not foreseen"*. This made it possible to deviate from the existing design in the event of an unexpected obstacle.

Table 2. Identified types of actions that enhance the reliability of the project team.

HRO principles	Reliability-enhancing types of actions
Preoccupation with Failure	1. Conducting preparatory research and taking actions based on expertise to prevent disruptions from occurring
Reluctance to Simplify	2. Actively discussing different viewpoints on design choices
	3. Applying expert supervision on the construction site to notice disruptions
Sensitivity to Operations	4. Utilising informal communication about design choices to exchange information within the project team
Commitment to Resilience	5. Utilising expertise and skills in a project-specific context to implement DH networks
	6. Applying expertise and skills to make decisions and adjustments on-site
Deference to Expertise	7. Involving expertise in order to quickly respond to unexpected disruptions

Table 3. Identified types of actions and non-actions that reduce the reliability of the project team.

HRO principles	Reliability-reducing types of actions and non-actions
Preoccupation with Failure	1. Lacking a proactive attitude in learning after experiencing disruptions
	2. Falling short in updating operational processes after disruptions occur
Reluctance to Simplify	3. Making assumptions to drive project progress to ensure timely completion
	4. Missing detailed work instructions and uniform documentation
Sensitivity to Operations	5. Missing out on the alignment and integration of interrelated operational processes

4.1.2. Actively discussing different viewpoints on design choices

To minimise disruptions during the construction phase, designs are cross-checked for errors and potential issues related to the constructability of the design. The senior engineer explained, *"The drawings are internally reviewed in accordance with the four-eyes principle, by myself or another professional with expertise related to the project"*. This controlling mechanism is used to ensure that at least two individuals approve of a certain action before it is taken. The goal is to reduce the number of errors that could be caused by an engineer overlooking details or lacking expertise.

The senior engineer explained that in addition to the four-eyes principle, the team also uses a cross-discipline control approach to identify potential disruptions at an early stage, *"When a drawing is completed, it is sent to them (site engineers and foremen) to assess whether it is technically feasible or not"*. By involving experts from different disciplines, the team address potential disruptions before they become major issues during construction.

The site engineer and team manager emphasised the importance of cross-discipline control for checking material orders for pre-insulated pipes and fittings. The team manager explained that delivery times for prefabricated pipes can range from four weeks for standard pipelines and fittings to thirteen weeks if additional alloys are required in the steel service pipe. The site engineer underlined that incorrect orders and shortage of material can cause significant project delays, "*We can run into problems when something breaks, we simply have a thirteen-week delivery time".* Therefore, they want to utilise the full expertise of the project team to guide the ordering of additional and spare parts in preparation for the possibility of unexpected part breakages.

4.1.3. Applying expert supervision on the construction site to notice disruptions

The project team considers the foreman to be the most crucial link in identifying disruptions in time. The foreman is responsible for converting the design into a construction plan and schedule that takes into account any constraints identified during the engineering phase. On a daily basis, the foreman must oversee the execution of construction plans as designed, without the need for adjustments or rework. This requires careful attention to detail for possible deviations from the pre-planned design.

The foreman's ability to anticipate and prevent potential problems largely relies on their ability to communicate effectively with their team. By maintaining open and frequent communication with the construction crew, the foreman can stay informed about potential issues and take action. This continual verbal interaction is essential for ensuring the success of the project, as described by the foreman, *"I just think it is important that you are often on the construction site and talk a lot with the guys (about deviations from pre-planned schedules)".*

The foreman's role relies heavily on their experience and practical knowledge, rather than on formal training or explicit knowledge. As a result, the role is typically filled by someone with extensive experience in the construction industry. However, this also means that the role is not easily transferable or replaceable, and the success of the project may depend heavily on the individual skills and expertise of the foreman.

4.1.4. Utilising informal communication about design choices to exchange information within the project team

The professionals in the project team often communicate in passing or during meetings. This way of informal communication is possible as explained by the foreman, *"I think that because we have control over the entire vertically integrated process, the lines are shorter. The advantage is that we (engineers, site engineers, and foremen) are situated in close proximity, enabling easy communication"*. This way of communication within the project team was emphasised by the foreman, *"The contracting department (consisting of site engineers and foremen) receives the transfer form from the engineers. We are closely interconnected and have weekly meetings about the projects".* Frequent communication across disciplines helps identify potential problems and ensures that the design is fully aligned and that the entire team is aware of possible constraints during construction.

The site engineer underlined the importance of frequent communication within the team in order to consider all interests and take this into account during the engineering phase, *"In fact, the entire plan is worked out and discussed with us (site engineers and foremen) before it actually is transferred to us as assignment".* To ensure that documents are transferred correctly and with the necessary context, frequent communication is important, as well as a physical consultation moment for document transfer. The site engineer explained, *"The transfer of documents is essential for this (clear project handover during a meeting)".*

During the construction phase, the engineers are involved in order to gain insight into the practicalities of the work. The foreman and junior engineer emphasised the importance to visit project locations, the foreman stated, *"You can capture activities to a certain extent, but you learn most by doing it, going along, and by watching. You just need to have a picture of each other's work and also of the complexity that comes with it"*. The junior engineer added, *"If a disruption has occurred, the foreman calls me and asks if I can come by to see what the influence is of the process disruption"*.

Frequent informal communication can be useful for quickly sharing information and adjusting activities, but it also creates a dependency on verbal information which can lead to incomplete or inaccurate sharing of information. On the other hand, step-by-step plans can support information sharing and can be optimised.

4.1.5. Utilising expertise and skills in a project-specific context to implement DH networks

The project team carefully plans and conducts the necessary preliminary research for each project and adapts their designs to address the unique challenges posed by each project's specific constraints. The senior engineer stated, *"The issue is that every project is different, and the problem is different every time as well. It is and will remain custom work"*. To provide customised solutions for each project, the team places a strong focus on utilising the expertise and experience of its professionals. The senior engineer highlighted that experience is a crucial component in making project-specific designs, *"I think processes should be well described, but I also think that engineering is an experiential profession"*. With this statement, he implies that while processes can serve as a guide, ultimately it is experience and expertise that drive the development of custom solutions for project-specific issues.

The team uses preparatory measures to cope with constraints during the preparation phase, however predominantly expertise is the driving force behind their actions. The foreman stated that they approach every situation with the mindset that an on-site solution may be necessary as they do not fully rely on pre-planning and preliminary research, *"If, based on a soil investigation, the project is located two meters away from a contamination, then we (theoretically) have no contamination. But if we eventually come across that contamination, we will have to inform the right people at that moment".* Despite thorough examination, it is not always possible to identify every underground feature or potential hazards, such as unrecorded cables or pipelines, or undetected ground pollution. The foreman stated, *"In existing situations, we always come across things that are not on the drawing. We can only* *deal with it the moment we encounter it"*. As a result, the team places more emphasis on their own expertise and skills, rather than relying on extensive preliminary research to anticipate disruptions.

4.1.6. Applying expertise and skills to make decisions and adjustments on-site

Professionals are expected to use their expertise to implement the design and create a functional network. The technical drawings serve as a general reference for construction crews on-site as they construct the pipeline route, but they are not considered formal guidelines. The professionals are allowed to deviate from these drawings and use their own common sense and expertise to guide their work. This approach was acknowledged by the senior engineer, who said, *"I think based on experience the guys (practitioners on-site) know how to do it"*. The client affords the team the latitude to deviate from the design in the event of unforeseen circumstances, and trusts in their ability to utilise expertise and judgment to solve these issues. As the site engineer explained, *"They (the client) have faith in our expertise to deal with the situation creatively and smartly"*.

This approach gives the team the ability to take charge on-site and find solutions to any issues that may arise. For example, during a project that included the installation of a fire hydrant near a DH pipeline, it was determined by the team that it would be more practical to relocate the fire hydrant. The site engineer communicated this idea to the owner of the fire hydrant, *"We just call the organisation and tell 'hey, guys this is our problem, maybe it is useful, and also much more practical for you if you put that fire hydrant over there'"*. This adaptability enables the team to be flexible and resilient to disruptions and enables them to recover quickly.

4.1.7. Involving expertise in order to quickly respond to unexpected disruptions

The team relies on their expertise and skills to handle unexpected situations. Decision-making is based on input from all professionals, regardless of their hierarchical rank. In the case of specialist activities, such as horizontal directional drilling, professionals in this field are involved to support and handle related tasks on the project. In the event of disruptions on-site, practitioners offer their own suggestions for solutions. If the practitioners are unable to solve the issue, they consult with the foreman for guidance. As the foreman stated, *"They know themselves what to do, and if there are any problems they will call"*.

When issues arise, the foreman seeks assistance from his informal connections in identifying solutions, *"The most important thing about working in construction is that you have good contacts with, for example, municipalities, water boards, and clients"*. These contacts are useful in situations to adjust and reroute existing utility networks. DH pipe routes cannot be easily adapted without pre-designed routes and pre-fabricated fittings due to the thermal expansion of the network and standards for welding and insulating the pipe joints. Therefore, it is often a more feasible option to reroute existing cables due to their relative flexibility or to reroute uninsulated pipes as the necessary fittings for these pipelines are often readily available. The foreman explained, *"If we run into something out in the field, we cannot simply wait thirteen weeks. So, we try another discipline to adapt by making a saddle bend"*. Having a network of contacts can allow for quick responses to disruptions, as it enables access to a range of resources and expertise.

In the event of disruptions on the construction site, the site engineers are typically consulted to assist in solving them. However, the engineers are often not informed about these changes, as explained by the team manager, *"Then we solve that on-site, the site engineers will be involved, however, this is not reported to the engineers"*. Only if changes to the technical design of the network are necessary engineers are involved. Such as adjustments to the technical design for thermal expansion, engineers are asked to review the design and perform the necessary calculations to ensure that the network complies with the applicable standards.

4.2. Types of actions and non-actions that reduce reliability

4.2.1. Lacking a proactive attitude in learning after experiencing disruptions

The sharing of disruptions that occur within a project among all project members is not given sufficient attention. According to the foreman, the decision to report a disruption depends on the extent of the impact, *"Major clashes that are encountered in the design phase are discussed immediately because we have to look for the right solution with the engineer. However, small deviations such as 'we went two centimetres down or to the side because we came across a cable duct', those we do not even discuss".* When there are no disruptions or when they are easily solved on-site, they are seldom reported. The foreman stated, *"If all goes well you will not hear anything, it is that simple"*. The senior engineer confirms, *"I actually always assume 'no news is good news', because they know where to find me if necessary"*. It appears that the project team lacks a proactive mindset to gain knowledge from disruptions in order to respond to this in subsequent projects.

In the event that disruptions are discussed, communication takes place informally, rather than through formal examination. The senior engineer described the unstructured way of communicating as, *"The foreman just enters the department (to share the issue)"*. The junior engineer described communicating during disruptions as, *"The foreman indignantly storms in and asks, 'how is this possible?'"*. When issues are briefly mentioned, discussions about them often come to an end. These disruptions are rarely addressed in project evaluations or meetings where they can be thoroughly examined and analysed. The team manager emphasised, *"Project evaluations are performed too infrequently"*.

Because evaluations are scarcely performed, disruptions remain unnoticed and lessons are not learned from mistakes that are made. For instance, disruptions are rarely actively recorded and documented, resulting in a lack of measures to prevent future disruptions. As the senior engineer noted, *"There is not something like a lessons learned report drawn up"*. At present, the project team prefers informal communication over formal evaluations or reports on lessons learned, therefore disruptions are only briefly and informally acknowledged. In light of this, the project team typically addresses and solves issues as they arise.

4.2.2. Falling short in updating operational processes after disruptions occur

The project team addresses disruptions as they occur, but without making any adjustments to the underlying approach or operations. This currently leads to recurring disruptions. A major challenge in improving these processes is the lack of clear documentation of the processes. Methods and processes applied during projects are based on experiences from previous projects. The frequent lack of documentation or the current status of processes leads to a deficiency in clear understanding and instructions for their proper execution. This hinders the capacity for optimisation and makes it more challenging to reduce disruptions in a structural manner. Furthermore, it poses difficulties in sharing knowledge and training new professionals.

If process descriptions are accessible, they are frequently not utilised as professionals often rely on their expertise. As a result, processes are rarely updated following disruptions. Even when updates are made, they are usually not done in a systematic and active manner. The senior engineer explained, *“Everyone who is working in that process at that moment will receive an e-mail to inform that we (as a project team) have changed that (the process)”*. This highlights that if processes are already in use, they are not actively managed in a central system to keep them up to date, rather the team is informally apprised of modifications.

4.2.3. Making assumptions to drive project progress to ensure timely completion

During the initial stage of a project, the team may be compelled to rely on assumptions as a result of an unclear scope, the absence of signed contract documents, or a lack of reliable data, such as incomplete or incorrect information regarding existing cables and pipelines. The senior engineer explained, *“It is sometimes the case that a conceptual design is made, while minimal information is available”*. In these cases, the team relies on assumptions to initiate the project. Reliance on assumptions is often necessitated by the need to place orders for pre-insulated pipes in a timely manner, in order to commence construction activities as scheduled.

The pre-insulated pipes and fittings can have delivery times of up to thirteen weeks, which can lead to rushed decisions if arrangements have already been made for the commissioning of the network. The team manager stated that as a result, orders may need to be placed based on incomplete or preliminary designs, *“We are almost automatically forced to make assumptions, to possibly place orders based on a preliminary design”*. Placing orders on the basis of preliminary designs carries the risk that disruptions may occur during the construction phase that could have been anticipated during a final design phase, or that the client may not agree with the design.

Furthermore, assumptions are often formed on the basis of past experience and prior projects. The team then utilises their expertise to determine the feasibility of executing the project as intended. Frequently, initial inventory studies are deemed unnecessary, owing to previous projects not requiring such evaluations. However, this approach can oversimplify the situation and leave the team less aware and unprepared for disruptions that may occur.

4.2.4. Missing detailed work instructions and uniform documentation

Work instructions and procedures can greatly benefit practitioners by providing them with a step-by-step guide. This helps to ensure that all necessary steps are followed, reducing the risk of something being missed. As described by the senior engineer, *“If we (engineers) have clear work instructions, it works a lot better because we can proceed through the steps”*. However, the project team in general lacks comprehensive work instructions, which poses a risk of tasks and actions being overlooked. Furthermore, the absence of such instructions also poses a challenge in effectively training new employees. According to the project coordinator, new employees are currently trained through a combination of on-the-job learning and practical experience, *“Usually they simply receive an introduction from our technical specialist”*. This introduction involves receiving training from a senior engineer and actively participating in projects and learning through hands-on experience.

Upon completion of training through these implicit methods, there is a risk that documents containing project information will not be conveyed with complete accuracy, resulting in the potential loss of important details. This is due to the lack of structured and uniform storage of documents, which can lead to the risk of using incorrect documents in subsequent steps of the process. For example, unique identification numbers are rarely assigned to technical drawings and material lists. Version control is often missing or rarely updated every time a change is made. The senior engineer emphasised, *“If we make a list of materials, this one does not contain any date or version number”*. The senior engineer explained that cross-referencing between documents makes sense, *"Then we can still have an error, but we cannot have those asinine errors that we have updated the drawing and not the material list”*. The other senior engineer suggests that it would be beneficial to utilise a single system for document exchange as a team, instead of relying on informal document transfer and the use of disparate systems across departments, *“We (as a project team) simply have to opt for a clear ERP (Enterprise Resource Planning) system in which projects are easily archived and managed”*. A project management system, which can be used as a tool to plan, organise, and manage projects, can provide a solution for monitoring the process and making adjustments where necessary.

4.2.5. Missing out on the alignment and integration of interrelated operational processes

The organisation suffers from a deficiency in communication and comprehension regarding the interconnectedness of various operational processes and systems. This is partially ascribed to the insufficiency of process descriptions being documented, resulting in ambiguity regarding the duties and tasks of each practitioner. Even though the practitioners form a cohesive project team, there is a clear separation of tasks between those involved in the design and those involved in construction activities. Each practitioner primarily concentrates on their individual responsibilities, rather than on the project as a whole. This lack of collective responsibility can exacerbate the lack of coordination and integration within the organisation.

The separation of responsibilities for tasks is also evident in the alignment of activities and the handover of documents. There is a lack of clarity regarding the boundaries of activities, which leads to a lack of coordination among different tasks. An example of this lack of coordination is when an engineer creates a bill of materials based on the design specifications but does not include pricing. The junior engineer stated, *“The site engineer still has to make adjustments in terms of costs and prices on this list each time”*. This requires the site engineer to go through the lists and add prices later and place the actual order. The engineer emphasised, *“We (as a project team) are experiencing a degree of duplication in that aspect”*. This lack of coordination can be time-consuming and inefficient for the organisation.

4.3. Practical mechanisms to enhance project reliability

During the interactive part of the workshop session, the participants shared their perceptions, ideas and opinions on how practical mechanisms can improve their capabilities to enhance reliability within projects. Therefore, the mechanism focused on improving the current reliability-reducing types of activities. Based on this workshop session seven practical mechanisms were formed that can promote a proactive attitude when anticipating process disruptions, as well as procedures and documents that can provide guidance when anticipating project activities. Table 4 shows the relationship between the five reliability-reducing types of actions and the mechanisms to enhance reliability within projects. Figure 1 illustrates the mechanisms in the context of the project organisation and indicates where in the process the mechanisms should be implemented.

The first five mechanisms provide support in setting up an appropriate organisational structure by implementing administrative and organisational processes. The mechanisms that contribute to this are process descriptions, work instructions, uniform documentation, and project intake and handover forms. The last two mechanisms are aimed at enhancing anticipation capabilities by means of adopting a proactive attitude. This attitude should encourage professionals to learn from previous disruptions and apply that knowledge to better manage and address similar issues in future projects. Proposed mechanisms include site visits and project evaluations. The following sections provide an explanation of all seven mechanisms.

The first mechanism is to adhere to pre-established processes for completing tasks and activities. Currently, this is accomplished by utilising the knowledge and experience gained from previous projects, but this approach can make it challenging to identify and address disruptions as they arise. By documenting and clearly outlining the steps in a process, it becomes easier to identify and address deviations and improve the process for future projects, reducing the likelihood of similar disruptions occurring again.

Process descriptions offer a high-level overview of processes, while work instructions offer detailed, step-by-step guidance for completing a task. Therefore, the second mechanism includes work instructions. These instructions ensure that all necessary steps are followed and minimise the risk of information being overlooked. Work instructions promote structure and consistency in task execution within a project team and can aid in training new professionals. They also serve as a clear and organised means of communicating process details, helping to eliminate variations in detail among different professionals.

The utilisation of document numbering and version control represents the third mechanism for enhancing document organisation and facilitating organised document transfer and archival. The implementation of document numbering lessens the probability of transferring incorrect documents, and version control guarantees that the project team is using the same version of a document, while also accurately documenting and tracking any changes. Furthermore, the establishment of cross-references between documents lessens the potential for errors stemming from the use of incorrect documents. These mechanisms can serve to improve the efficiency and precision of document management within a project.

The fourth mechanism is the use of a project intake document. The intake document functions as a checklist to confirm that all vital information is acquired and serves to clarify the level of detail required for activities and the deliverables to be submitted. This can help to mitigate the risk of assumptions being made as a result of missing information or documents, and ensures that a project commences with all the necessary information. Additionally, the intake document can aid in streamlining the project process by clearly outlining the steps and tasks that must be completed.

The fifth mechanism is the use of a project handover document. This document aims to facilitate the structured transfer of information from the engineering phase to the construction phase. The document provides a summary of the documents being transferred, including their most recent versions, and serves as a table of contents for referencing documents. Additionally, it displays key information at a glance, making it a useful document for efficiently organising and accessing valuable information during the construction phase.

The sixth mechanism is the active involvement of engineers in the construction phase of a project through regular site visits. These visits serve to verify that the project is being executed according to the plans and specifications outlined in the technical drawings. By closely monitoring the progress of the project, any deviations from the original design can be identified and addressed in future projects. Furthermore, engineers can gain valuable knowledge and insight through active participation in the construction phase, allowing them to assess the structural feasibility of the project and evaluate how the project environment may impact construction activities.

The seventh mechanism for ensuring the success of a project involves conducting regular evaluations of the project. These evaluations allow for the identification of disruptions and deviations from established processes, and provide opportunities for addressing these issues through lessons-learned reports. By regularly evaluating the project, the team can continually improve and learn from their experiences.

When implementing documents or processes it is important that these documents are accessible to all practitioners within the project team and are up-to-date. The documents must therefore be stored centrally and actively managed.

5. Discussion

The project team utilises a combination of both anticipatory and containment principles to cope with disruptions. However, in coping with these disruptions, they frequently employ implicit knowledge and improvisation. To minimise the negative impact of disruptions, professionals often use containment principles by applying their expertise on-site. The project team is able to quickly come up with new strategies to address disruptions because of their expertise and skills. Their readiness for disruptions is based on their past experiences, which have taught them that adjustments will be necessary for complex environments where unforeseen situations are likely to arise. While this approach allows the team to address disruptions on-site, it may also lead to less consideration of potential challenges during the design phase.

The project team not only undertakes actions that enhance reliability but also acknowledges actions and non-actions that negatively impact reliability. These actions and reactive attitudes are linked to the lack of applying and following anticipatory principles. The team uses informal assessments or reviews to identify errors and issues but does not proactively consider potential disruptions and develop guidelines for coping with them in upcoming projects. Anticipatory actions are typically only

Table 4. Practical mechanisms to enhance project reliability. Reliability-reducing types of actions and non-actions are adopted from Table 3.

Reliability-reducing types of actions and non-actions		Practical mechanisms
1.	Lacking a proactive attitude in learning after experiencing disruptions	① Process descriptions; ⑥ Site visits; ⑦ Project evaluations
2.	Falling short in updating operational processes after disruptions occur	① Process descriptions; ⑦ Project evaluation
3.	Making assumptions to drive project progress to ensure timely completion	④ Project intake; ⑤ Project handover
4.	Missing detailed work instructions and uniform documentation	② Work instructions; ③ Document numbering and version control
5.	Missing out on the alignment and integration of interrelated operational processes	① Process descriptions; ⑥ Site visits; ⑦ Project evaluations

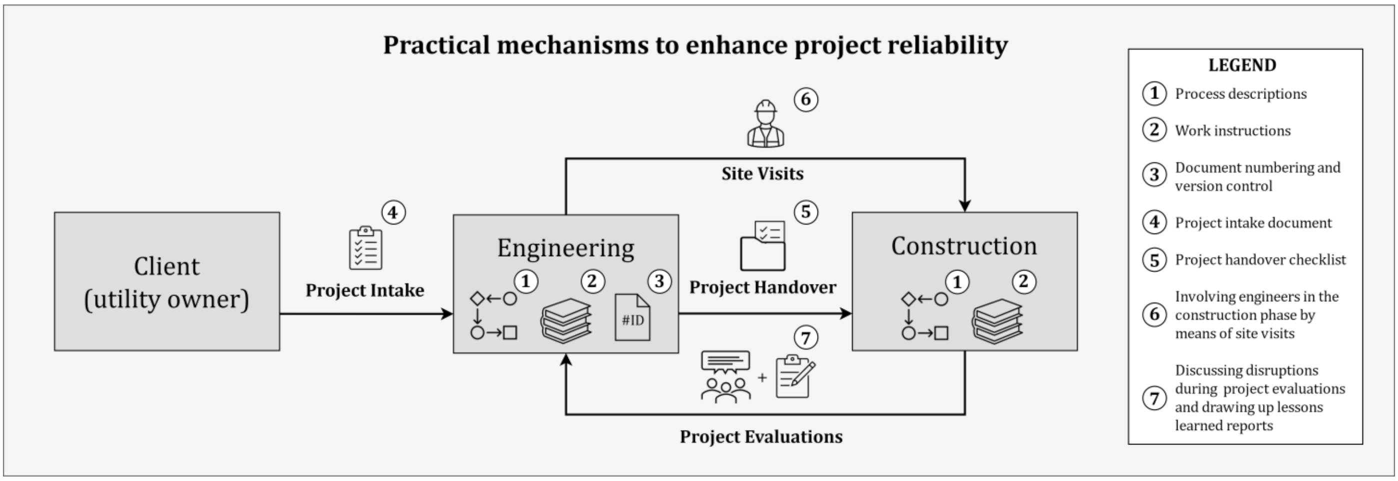

Figure 1. Visual representation of the practical mechanisms to enhance project reliability.

undertaken when deemed necessary by a professional with expert knowledge and experience, rather than being carried out according to established protocols. The team is aware that disruptions may arise, but they are not prepared for them due to a lack of a proactive learning attitude and inadequate organisational structures. This leaves the projects vulnerable to disruptions.

It appears that the level of anticipation measures is strongly influenced by the size and complexity of the project. In cases where a project is considered to be relatively simple and straightforward, it is less likely that the project team will take the time to anticipate and prepare for potential disruptions. Instead, they focus on completing the project with their expertise and skills, without taking the time to plan for potential disruptions. A possible explanation for the lack of initiative in extracting lessons from disruptions may be the belief that each project situation is unique and can only be solved through on-site expertise and skills, rather than following established process descriptions. Thereby, the project team does not immediately see the need to change their approach because it has worked well for them in the previously completed projects. They believe that their expertise and experience enable them to successfully tackle any challenges.

When the project team is placed in the context of mindful organising, it is observed that they efficiently utilise containment principles, enabling them to adapt readily to the project situation. However, they might place excessive emphasis on containment principles and neglect to focus on anticipation principles as well. While mindful organising does utilise containment principles that enable them to contain and bounce back from disruptions mindfully, in order to deal with the unexpected in a variable manner (Weick & Sutcliffe, 2007). It also employs anticipation principles, in terms of administrative and organisational processes to manage tasks and foresee these events by sensing and stopping disruptions in an early stage (Weick & Sutcliffe, 2007). To achieve higher reliability and improve performance, the project team should maintain a more balanced division in applying anticipation and containment principles.

It is important to consider the limitations of this study when interpreting the findings. The first limitation of this study is that organisations that apply HRO typically involve mature project organisations with established processes and structures (Weick & Sutcliffe, 2007). These established structures serve as a foundation and starting point for implementing the HRO principles and improving processes and practices. However, the emerging project organisation of the project team in this study did not have established structures to serve as a starting point. It seems that the team is still in the process of determining the most effective organisational structure and project setting for their organisation.

The second limitation is related to practical mechanisms proposed to enhance project reliability. During the workshop session, the professionals discussed whether the practical mechanisms were seen as appropriate and useful for enhancing their anticipation capabilities. This session served as a starting point for discussing the practical mechanisms and their implementation. However, these mechanisms have not yet been implemented, and it remains to be determined whether they will have the desired effect of enhancing project reliability.

The discussion ends with the recommendation for project teams to implement the proposed practical mechanism to improve actions and processes, and enhance project reliability. Future research could examine whether the mechanisms are effective in minimising process disruptions and improving project efficiency. In addition, further research will be necessary to explore how to facilitate the transition from implicit knowledge and skills to explicit ones, in order to make project activities transferable and facilitate the training of new professionals.

6. Conclusion

The construction of DH networks involves placing large rigid pipelines in the crowded urban subsurface, which present unique challenges. To optimise the efficiency of these operations, it is needed to minimise disruptions and reduce delays as much as possible. This research assessed how a project team in the field of DH copes with disruptions through the use of the mindful organising lens. The study identified seven activities that enhance reliability and five that reduce reliability.

The results of the interviews and observations conducted during this study revealed that the project team employs a combination of anticipatory and containment principles to manage disruptions. The actions identified indicate that the use of containment principles by the project team allows for a high level of adaptability in addressing issues that arise during the project. This is achieved by utilising the team's implicit knowledge and expertise to cope with disruptions and minimise delays. However, the identified actions and non-actions that reduce the reliability of the team were found to be related to a lack of implementation and adherence to anticipatory principles. It appears that the team falls short in implementing administrative and organisational processes to effectively manage tasks and anticipate disruptions. As a result, the team responds to disruptions instead of proactively planning for them, making projects more vulnerable to disruptions.

The effective scaling of DH network deployments necessitates the use of both containment and anticipatory principles in order to prepare for and learn from unexpected disruptions, and improve future performance. This requires the implementation of explicit strategies to minimise disruption and enable the training of new professionals. As a result, this study has formulated seven practical mechanisms to enhance project reliability, which can serve as a stepping stone towards improved project efficiency. These mechanisms aid in the establishment of an appropriate organisational structure and improve anticipation through more proactive efforts to learn from past disruptions, and effectively manage and address such events in future projects.

This research not only provides practical insights to enhance project reliability but also advances the field of HRO studies by examining an organisation that has not yet established clear organisational structures. The project team in this study is part of an emerging project organisation, where organisational structures are still evolving. The research contributes to the scientific literature by assessing HRO in the context of an organisation that is still improving its organisational maturity by identifying effective organisational processes.

Since many new practices in the energy transition involve similar challenges, research in this area may also be relevant to other sectors that are seeking to scale up construction processes reliably. This makes the scientific contribution of this research potentially applicable to a wide range of fields within the energy transition sector.

References

Boesten, S., Ivens, W., Dekker, S. C., & Eijdems, H. (2019). 5th generation district heating and cooling systems as a solution for renewable urban thermal energy supply. *Advances in Geosciences*, *49*, 129–136. https://doi.org/10.5194/adgeo-49-129-2019

Connolly, D., Lund, H., Mathiesen, B., Werner, S., Möller, B., Persson, U., Boermans, T., Trier, D., Østergaard, P., & Nielsen, S. (2014). Heat Roadmap Europe: Combining district heating with heat savings to decarbonise the EU energy system. *Energy Policy*, *65*, 475–489. https://doi.org/10.1016/j.enpol.2013.10.035

Connolly, D., Mathiesen, B. V., Østergaard, P. A., Möller, B., Nielsen, S., Lund, H., Trier, D., Persson, U., Nilsson, D., & Werner, S. (2012). *Heat Roadmap Europe 1: First Pre-Study for the EU27*. http://vbn.aau.dk/en/publications/heat-roadmap-europe-2050-second-prestudy-for-the-eu27%28306a5052-a882-4af9-a5da-87efa36efeaa%29.html

de Bruijne, M., & van Eeten, M. (2007). Systems that Should Have Failed: Critical Infrastructure Protection in an Institutionally Fragmented Environment. *Journal of Contingencies and Crisis Management*, *15*(1), 18–29. https://doi.org/10.1111/j.1468-5973.2007.00501.x

Elbeltagi, E., Hegazy, T., & Eldosouky, A. (2004). Dynamic Layout of Construction Temporary Facilities Considering Safety. *Journal of the Construction Division and Management*, *130*(4), 534–541. https://doi.org/10.1061/(asce)0733-9364(2004)130:4(534)

Enya, A., Pillay, M., & Dempsey, S. (2018). A Systematic Review on High Reliability Organisational Theory as a Safety Management Strategy in Construction. *Safety*, *4*(1), 6. https://doi.org/10.3390/safety4010006

European Commission. (2022). *District heating and cooling in the European Union : overview of markets and regulatory frameworks under the revised Renewable Energy Directive*, Publications Office of the European Union. https://data.europa.eu/doi/10.2833/962525

Fahl, U., & Dobbins, A. (2017). District Heating in Europe. *Europe's Energy Transition - Insights for Policy Making*, 249–259. https://doi.org/10.1016/b978-0-12-809806-6.00029-8

Hamzeh, F. R., Faek, F., & AlHussein, H. (2018). Understanding improvisation in construction through antecedents, behaviours and consequences. *Construction Management and Economics*, *37*(2), 61–71. https://doi.org/10.1080/01446193.2018.1497189

Jeong, H. S., Abraham, D. M., & Lew, J. J. (2004). Evaluation of an Emerging Market in Subsurface Utility Engineering. *Journal of Construction Engineering and Management*, *130*(2), 225–234. https://doi.org/10.1061/(asce)0733-9364(2004)130:2(225)

La Porte, T. R. (1996). High Reliability Organizations: Unlikely, Demanding and At Risk. *Journal of Contingencies and Crisis Management*, *4*(2), 60–71. https://doi.org/10.1111/j.1468-5973.1996.tb00078.x

Lake, A., Rezaie, B., & Beyerlein, S. (2017). Review of district heating and cooling systems for a sustainable future. *Renewable and Sustainable Energy Reviews*, *67*, 417–425. https://doi.org/10.1016/j.rser.2016.09.061

Leedy, P. D., & Ormrod, J. E. (2015). *Practical Research: Planning and Design* (11th ed.). Pearson Education Limited.

Lucko, G., Said, H. M. M., & Bouferguene, A. (2014). Spatially Constrained Scheduling with Multidirectional Singularity Functions. *Construction Research Congress 2014*. https://doi.org/10.1061/9780784413517.148

Lund, H., Möller, B., Mathiesen, B., & Dyrelund, A. (2010). The role of district heating in future renewable energy systems. *Energy*, *35*(3), 1381–1390. https://doi.org/10.1016/j.energy.2009.11.023

Lund, H., Werner, S., Wiltshire, R., Svendsen, S., Thorsen, J. E., Hvelplund, F., & Mathiesen, B. V. (2014). 4th Generation District Heating (4GDH). *Energy*, *68*, 1–11. https://doi.org/10.1016/j.energy.2014.02.089

Maria Jebamalai, J., Marlein, K., Laverge, J., Vandevelde, L., & van den Broek, M. (2019). An automated GIS-based planning and design tool for district heating: Scenarios for a Dutch city. *Energy*, *183*, 487–496. https://doi.org/10.1016/j.energy.2019.06.111

Mitropoulos, P., & Cupido, G. (2009). Safety as an Emergent Property: Investigation into the Work Practices of High-Reliability Framing Crews. *Journal of Construction Engineering and Management*, *135*(5), 407–415. https://doi.org/10.1061/(asce)co.1943-7862.0000002

Netbeheer Nederland. (2017). Position Paper NBNL Herziening Warmtewet. *Netbeheer Nederland*. https://www.netbeheernederland.nl/_upload/RadFiles/New/Documents/20171207_Position_Paper_NBNL_Herziening_Warmtewet.pdf

olde Scholtenhuis, L. L., & Dorée, A. G. (2013). Welcoming high reliability organising in construction management. In S. D. Smith, & D. D. Ahiaga-Dagbui (Eds.), *Proceedings of the 29th Annual ARCOM Conference, 2-4 September 2013, Reading, UK,* Association of Researchers in Construction Management, pp. 939-948

olde Scholtenhuis, L. L., Hartmann, T., & Dorée, A. G. (2016). Testing the Value of 4D Visualizations for Enhancing Mindfulness in Utility Reconstruction Works. *Journal of Construction Engineering and Management*, *142*(7), 04016015. https://doi.org/10.1061/(asce)co.1943-7862.0001126

Oommen, P. (2021). Performing disruption analysis for construction projects. https://www.hka.com/performing-disruption-analysis-for-construction-projects/

Paiho, S., & Saastamoinen, H. (2018). How to develop district heating in Finland? *Energy Policy*, *122*, 668–676. https://doi.org/10.1016/j.enpol.2018.08.025

Persson, U., & Werner, S. (2011). Heat distribution and the future competitiveness of district heating. *Applied Energy*, *88*(3), 568–576. https://doi.org/10.1016/j.apenergy.2010.09.020

Ram, M., Osorio-Aravena, J. C., Aghahosseini, A., Bogdanov, D., & Breyer, C. (2022). Job creation during a climate compliant global energy transition across the power, heat, transport, and desalination sectors by 2050. *Energy*, *238*, 121690. https://doi.org/10.1016/j.energy.2021.121690

Rijksoverheid. (2019). *Klimaatakkoord*. https://www.rijksoverheid.nl/documenten/rapporten/2019/06/28/klimaatakkoord

Roberts, K. H., & Bea, R. (2001). Must accidents happen? Lessons from high-reliability organizations. *Academy of Management Perspectives*, *15*(3), 70–78. https://doi.org/10.5465/ame.2001.5229613

Talebi, B., Mirzaei, P. A., Bastani, A., & Haghighat, F. (2016). A Review of District Heating Systems: Modeling and Optimization. *Frontiers in Built Environment*, *2*. https://doi.org/10.3389/fbuil.2016.00022

van der Stok, E. J. W. (2014). Quality Control Of Joint Installation In Pre-Insulated Pipe Systems. *The 14th International Symposium on District Heating and Cooling*. https://www.kiwa.com/4ad67c/globalassets/netherlands/kiwa-technology/downloads/12.3-ernst-van-der-stok-quality-control-of-joint-installation-in-preinsulated-pipe-systems.pdf

Vogus, T. J., & Sutcliffe, K. M. (2007). The Safety Organizing Scale. *Medical Care*, *45*(1), 46–54. https://doi.org/10.1097/01.mlr.0000244635.61178.7a

von der Tann, L., Metje, N., Admiraal, H., & Collins, B. (2018). The hidden role of the subsurface for cities. *Proceedings of the Institution of Civil Engineers - Civil Engineering*, *171*(6), 31–37. https://doi.org/10.1680/jcien.17.00028

Weber, C., Maréchal, F., & Favrat, D. (2007). Design and optimization of district energy systems. *Computer Aided Chemical Engineering*, 1127–1132. https://doi.org/10.1016/s1570-7946(07)80212-4

Weick, K. E. (2011). Organizing for Transient Reliability: The Production of Dynamic Non-Events. *Journal of Contingencies and Crisis Management*, *19*(1), 21–27. https://doi.org/10.1111/j.1468-5973.2010.00627.x

Weick, K. E., & Sutcliffe, K. M. (2007). *Managing the Unexpected: Resilient Performance in an Age of Uncertainty* (2nd ed.). Jossey-Bass.

Weick, K. E., Sutcliffe, K. M., & Obstfeld, D. (1999). Organizing for high reliability: Processes of collective mindfulness. In R. I. Sutton & B. M. Staw (Eds.), *Research in organizational behavior,* Vol. 21, pp. 81–123). Elsevier Science/JAI Press.

Werner, S. (2013). District Heating and Cooling. *Reference Module in Earth Systems and Environmental Sciences*. https://doi.org/10.1016/b978-0-12-409548-9.01094-0

Werner, S. (2017). International review of district heating and cooling. *Energy*, *137*, 617–631. https://doi.org/10.1016/j.energy.2017.04.045

Winch, G. M. (2009). *Managing Construction Projects* (2nd ed.). Wiley-Blackwell.

Zidane, Y. J. T., Johansen, A., Andersen, B., & Hoseini, E. (2015). Time-thieves and Bottlenecks in the Norwegian Construction Projects. *Procedia Economics and Finance*, *21*, 486–493. https://doi.org/10.1016/s2212-5671(15)00203-8