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Reasoning patterns in team-based idea generation

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1.1 POPULAR SCIENCE ABSTRACT

New products and services are developed by teams that often consist of designers, technicians, engineers, and other experts - depending on the type of products being developed. A critical stage of such design activity is the idea generation phase where groups of relevant people meet and create ideas for new solutions. Ideas developed here often have a major impact on the final product, as it is at this time that the space and frame for continuing design work is defined.

Therefore, it is important to understand the activity that occurs when ideas are developed. What is the basis for developing and selecting ideas? What thoughts, arguments, and experiences are brought into play? My approach in this dissertation is to investigate the reasoning patterns in the arguments used and the significance of such patterns for the idea generation activity and for ideas being chosen for further development, thus adding value to the overall design process.

Reasoning is a central cognitive function that determines how people make decisions and interpret the world. Since the 1970s, researchers have been interested in reasoning during design activity. They have used formal logical models to describe the patterns of thought by dividing them into so-called deductive, inductive and abductive types. Of these, particularly abductive reasoning is considered to be central to design activity, as this type allows to propose something new that by definition is central to design.

In the dissertation, I analyse how reasoning types appear in patterns when looking into what is being said in the team as they develop ideas and whether there is a correlation between these patterns and the quality that the design team later determines the ideas to have. I do this with conversational material taken from two development projects with five and four teams in each. The results of the analysis show that robust abductive-deductive patterns occur when oscillating between on the one hand introducing new perspectives and possibilities for solutions and, on the other hand, exploring these perspectives to create concrete solutions. Other patterns, such as the proportion of abductive reasoning, and the amount of reasoning, also influence the assessed value of ideas. Simple reasoning patterns have the greatest importance for short term design activity, i.e. when the individual

idea is created. Conversely, patterns with several types of reasoning and interactions have the greatest impact in the long term through the influence of how the later idea development unfolds.

The results confirm that reasoning can be analysed empirically as consisting of chains of micro-inferences including different types of reasoning that together characterise design activity. In practice, this means that the patterns found can be used in the development of techniques to improve the way a team performs in design activity. In the future, the results can be used to develop automated tools with artificial intelligence that can "listen in" on design activity, and, based on the reasoning patterns found, can suggest ways to adjust activities to achieve a better performance.

An important advantage of the developed analysis method is that there is only a limited need to understand the specific details of ideas being generated, as the method allows identifying the reasoning patterns from the words used in combination with some insight into design activity. Hence, the method is suitable for either automated tools or to design facilitators that may not hold specific in-depth knowledge about a design task. The limitation of the method is that it does not reveal specific influencing factors in design activity, such as personal attitudes, values and desires of those who partake in the design activity.

1.2 POPULÆRVIDENSKABELIGT ABSTRAKT

Nye produkter og services udvikles af teams som ofte består af designere, teknikere, ingeniører, og andre eksperter - afhængig af hvilken type produkter der udvikles. Et betydeligt stadie af deres fælles design aktivitet er selve ide-udviklingsfasen hvor grupper af relevante personer mødes og skaber idéer til nye løsninger. Idéer der udvikles her, får tit en stor betydning for det endelige produkt, da det er på dette tidspunkt, man fastlægger rammerne for løsningerne med udvælgelsen af de idéer der skal arbejdes videre arbejde med.

Derfor er det vigtigt at forstå den aktivitet der finder sted lige når idéer udvikles. På hvilket grundlag udvikles og udvælges idéer? Hvilke tanker, argumenter og erfaringer bringes i spil? Min tilgang i denne afhandling er at undersøge mønstrene i de ræsonnementer der anvendes og hvilken betydning mønstrene har for om idéer bliver udvalgt til videre udvikling.

At ræsonnere er en central kognitiv funktion som er afgørende for hvordan mennesker tager beslutninger og fortolker verden. Forskere har siden 1970'erne interesseret sig for ræsonnementer under design aktivitet. De har brugt formelle logiske modeller til at beskrive tankemønstrene ved at inddele dem i såkaldte deduktive, induktive og abduktive typer. Heraf er særligt abduktive ræsonnementer anset som helt centrale for design aktivitet, idet denne type tillader at skabe nyt, hvilket per definition er centralt i design som netop omhandler skabelsen af nye løsninger.

I afhandlingen analyserer jeg hvilke rækkefølger disse formelle typer optræder i, når man kigger nærmere på, hvad der bliver sagt i teamet mens de udvikler ideer, og om der er sammenhæng mellem rækkefølgen og den kvalitet, som designteamet senere tillægger idéen. Det gør jeg med samtale-materiale optaget fra to udviklingsprojekter med henholdsvis fem og fire teams i hvert projekt. Resultaterne af analyserne viser at robuste abduktive-deduktive mønstre især forekommer når der veksles mellem på den ene side at fremføre nye perspektiver og muligheder for løsninger, og på den anden side at udforske disse for at skabe konkrete bud på løsninger. Andre mønstre, som f.eks. andelen af abduktive ræsonnementer, og mængden af ræsonnementer, har en særlig indflydelse på den værdi idéerne senere tillægges. Simple ræsonnements mønstre har størst betydning for design

aktivitet på kort sigt, dvs. når den enkelte idé skabes. Modsat har mønstre der omfatter flere typer ræsonnementer og deres interaktioner har størst indflydelse på længere sigt gennem påvirkning af hvordan den senere idé-udvikling udfolder sig.

Resultaterne bekræfter at ræsonnementer kan opfattes empirisk som bestående af kæder af micro-ræsonnementer, af forskellige typer, der tilsammen kendetegner en design aktivitet. I praksis betyder det at de fundne mønstre kan anvendes i udvikling af teknikker til at forbedre den måde et team udfører deres design aktivitet, som ledere af design teams kan benytte sig af. I fremtiden kan man også forstille sig at automatiserede værktøjer med kunstig intelligens kan "lytte med" på en designsamtale, og ud fra de mønstre den finder, komme med forslag til hvordan man skal justere sine aktiviteter for at nå et bedre resultat. En væsentlig styrke ved metoden er, at man kun i begrænset behøver forstå hvad der snakkes om, men kan fange mønstrene i den måde og form hvorpå der ræsonneres. Begrænsningen er at det ikke bliver afdækket hvordan andre faktorer end de formelle og logiske spiller ind på mønsterdannelserne, eksempelvis personlige holdninger, værdier og ønsker hos de som deltager i design aktiviteten.

1.3 ACKNOWLEDGEMENTS

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1.5 PAPER OVERVIEW

This is a paper-based thesis. Table 1 presents the papers that have been published and authored as part of the research. All papers are attached in full in the appendices.

Paper	Publication target and status	Authors	Relation to thesis
Empirically analysing design reasoning patterns: Abductive-deductive reasoning patterns dominate design idea generation.	Design Studies (Published)	Cramer-Petersen, C.L., Christensen, B.T. & Ahmed-Kristensen, S.	Concerns Study 1 – WORKZ. Appears partially in Sections 3.1, 3.2, 4.2, 4.4 and 5.2.
Reasoning patterns and problem-solving behaviour: The effect on design micro-level activity in group idea generation.	**CoDesign** (Revise and resubmit)	Cramer-Petersen, C.L. & Ahmed-Kristensen, S.	Concerns Study 1 – WORKZ. Appears partially in Sections 3.2.2, 3.3, 4.4 and 5.2.
The relationship between idea value and reasoning patterns: An empirical study of company idea generation and	Research in Engineering Design (Revise and resubmit)	Cramer-Petersen, C.L. & Ahmed-Kristensen, S.	Concerns Study 2 – SMART. Appears partially in Sections 3.3, 4.5 and 5.3.

evaluation processes.			
Reasoning in Design: Idea Generation Condition Effects on Reasoning Processes and Evaluation of Ideas.	Proceedings of the 22nd Innovation and Product Development Management Conference (Published)	Cramer-Petersen, C.L. & Ahmed-Kristensen, S.	Not included in thesis as it was an early paper using only partial dataset and not contributing significantly more than other papers included.
Argumentation and Reasoning in Design: An Empirical Analysis of the Effects of Verbal Reasoning on Idea Value in Group Idea Generation.	Proceedings of the DESIGN 2016 14th International Design Conference (Published)	Cramer-Petersen, C.L. & Ahmed-Kristensen, S.	Concerns Study 2 – SMART. Appears partially in discussion of result, Section 5.3.

Table 1: Overview of papers that are part of the research, including publication status, authors and relation to present thesis.

2 INTRODUCTION

Design is activity pertaining to creating new solutions to problems (Cross & Roozenburg, 1992). Such design activity entails uncertainty and many possible avenues by which to reach solutions to problems (Ball, Onarheim, & Christensen, 2010). Problems that are addressed in design are inherently *wicked* in that there is a relationship between a defined problem and solutions produced (Rittel & Webber, 1973). This requires a perspective on design activity that is non-linear and reflects that solutions to problems are not true or false, but have different qualities (Buchanan, 1992), and that such qualities are understood differently by those involved in (or influenced by) design solutions (Bucciarelli, 2002).

When analysing design activity and the thinking of those involved, research is in part influenced by the cognitive science that draws from logic (Goel, 1988), human behaviour (Johnson-Laird, 2009), creativity research (Runco & Jaeger, 2012) and creative problem solving (Chan & Schunn, 2014) to explain how designers think and reason in design. Design cognition, as it is termed by Cross (2001), addresses design activity specifically and describes how problems and solutions co-evolve. This means that by working on a problem and generating solutions, the understanding of an initial problem evolves. Another term for this is emergence (Finke, 1996).

Acknowledging that design problems and solutions are not definitive phenomena for which 'true' solutions can be generated and that problems and solutions co-evolve, prevailing models for structuring and explaining design activity focus on prescribing stages of thinking and reasoning that ultimately provide solutions to problems (Dorst & Cross, 2001). Such thinking and reasoning is explained by several authors (e.g., Dong, Garbuio, & Lovallo, 2016; Gero & Kannengiesser, 2004; Hatchuel & Weil, 2008; March, 1976; Schön, 1991) who commonly describe different characteristics of the thinking that is applied in cycles or iteratively throughout design processes. A popular way to present iterative activity is through the terms of divergent and convergent cycles throughout design processes (Brown, 2009).

But how can these thinking processes and phases be further comprehended? This is a central question when attempting to understand and subsequently

support design activity in practice, whether through the development of methods, tools or techniques or other kinds of guidelines. One way to describe the thinking of designers is through exploring reasoning patterns during design activity. Reasoning determines how humans respond to situations in every aspect of their lives (Johnson-Laird, 2009). The reasoning of designers consists of trains of thought, including deliberation, arguing and making logical inferences (Rittel, 1987), and is therefore central to understanding and supporting design activity.

Since the 1970's, reasoning has received much attention in design research. At that time, reasoning was used to explain the way designers generate and evaluate design solutions using different types of reasoning akin to scientific discovery – that is, the formulation of hypotheses that are tested and later form the basis of generalisations (Magnani, 1995; March, 1976). The central concepts of reasoning drew from the works of Peirce (1980), who delineated deductive, inductive and abductive reasoning types as formally distinct ways of reaching conclusions from premises. The conceptualisation of reasoning in design was further developed during the 1990's, when the term of abductive reasoning was explored and defined as a core characteristic of any creative endeavour, and thus design activity. During this period, reasoning in design was largely investigated as a conceptual term, using prototypical examples of how designers apply primarily abductive reasoning. In recent years, there has been a re-emergence of investigating reasoning to better understand how design activity takes place, only this time with the realisation that empirical analyses of reasoning are necessary to advance understanding (Dong *et al.*, 2016; Koskela, Paavola, & Kroll, 2018).

As a consequence of the need for an empirical focus in order to understand reasoning, recent research highlights have spurred the conceptualisation of reasoning to be more informal and embedded in the social processes of design. In line with previous studies (Bucciarelli, 2002; Schön, 1991; Stumpf & McDonnell, 2002), design practice is described as a social process in which multiple perspectives, values and intentions are intertwined between the stakeholders involved in the development of new solutions. In engineering design, this typically constitutes team meetings between relevant employees. During such meetings, participants develop new ideas and plans in a process that entails arguing for ideas and perspectives that are based

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not only in 'rational' facts but established, for example, by laws of nature or the technical sciences (Buchanan, 1992). Arguments also reflect the perceived desires and needs of customers, users and other stakeholders who are (in)directly influenced by a designed solution and the values and desires of those doing design (Bucciarelli, 2002; Stumpf & McDonnell, 2002). When arguing for design ideas, design is enacted through the language used and thus has an active component in itself (Dong, 2007). This suggests that the way arguments are made, that is, how the reasoning is put forward, has a performative function, further adding to the complexity of design.

Hence, empirically studying reasoning in design involves perceiving the activity as a process of argumentation that reflects the underlying reasoning taking place (Rittel, 1987). Here, not only logically sound arguments reside, as alluded to above. To properly understand design, focus is suggested to be at a micro-level to capture such arguments as they transpire between those doing design (Rittel, 1987). That is, the analysis of the discourse between designers is central to understanding design activity.

Analysing verbal reasoning calls for methods other than those used in existing research to identify and analyse reasoning in design. The research presented in this thesis focuses on developing a method for identifying verbal reasoning at a micro-level. By applying this method to analysing design activity, the hope is to support the development of new methods, tools or techniques that can support design practice.

2.1   OVERVIEW OF RESEARCH

This section defines the central terms used in the research, provides a figure to illustrate and situate the research area and units of analysis, presents the overall aims of the research and, and exemplifies the kind of empirical data used in the research.

2.1.1   Terms and definitions

Table 2 shows a list of the central terms used throughout the thesis and a brief definition of their meaning.

Term	Definition
Reasoning	The mental operation of arriving at a conclusion from one or more premises.
Design activity	The activity done by people involved in designing.
Reasoning in design	The underlying thinking, deliberation and argumentation of people involved in design activity.
Reasoning pattern	A specific pattern of interaction between one or more occurrences of reasoning.
Verbal reasoning	An empirically derived form of reasoning that describes the reasoning taking place in natural dialogue between people.
Micro-level reasoning	The analysis of reasoning at the level of word phrases to ascertain instances of reasoning at the shortest possible meaningful length.
Idea	The utterance(s) (by a single person) in which a new idea is mentioned.
Idea aspect	Subsequent utterance(s) (by any person) relating to an initial idea.
Idea episode	The combined sequence of idea and idea aspects that together form an idea to a solution.
Design move	A distinguishable step of design activity that 'moves' an understanding of a problem and/or solution.

Breadth move	A short instance of design activity that proposes new perspectives or solutions.
Depth move	A short instance of design activity that explores perspectives or generates solutions.
Idea evaluation	The assessment of an idea according to a set of pre-defined criteria or dimensions.
Idea value	The contribution of a generated idea to an on-going creative process or product development process.
Idea theme	The specific part of a design solution space to which an idea relates.
Framing	The notion of a certain perspective or way to 'see' a design problem.

Table 2: Central terms used in the research and their definitions.

2.1.2　Research area model and units of analysis

Figure 1 illustrates the how the research presented in the thesis is situated in relation to product development and what aspects of design activity are investigated.
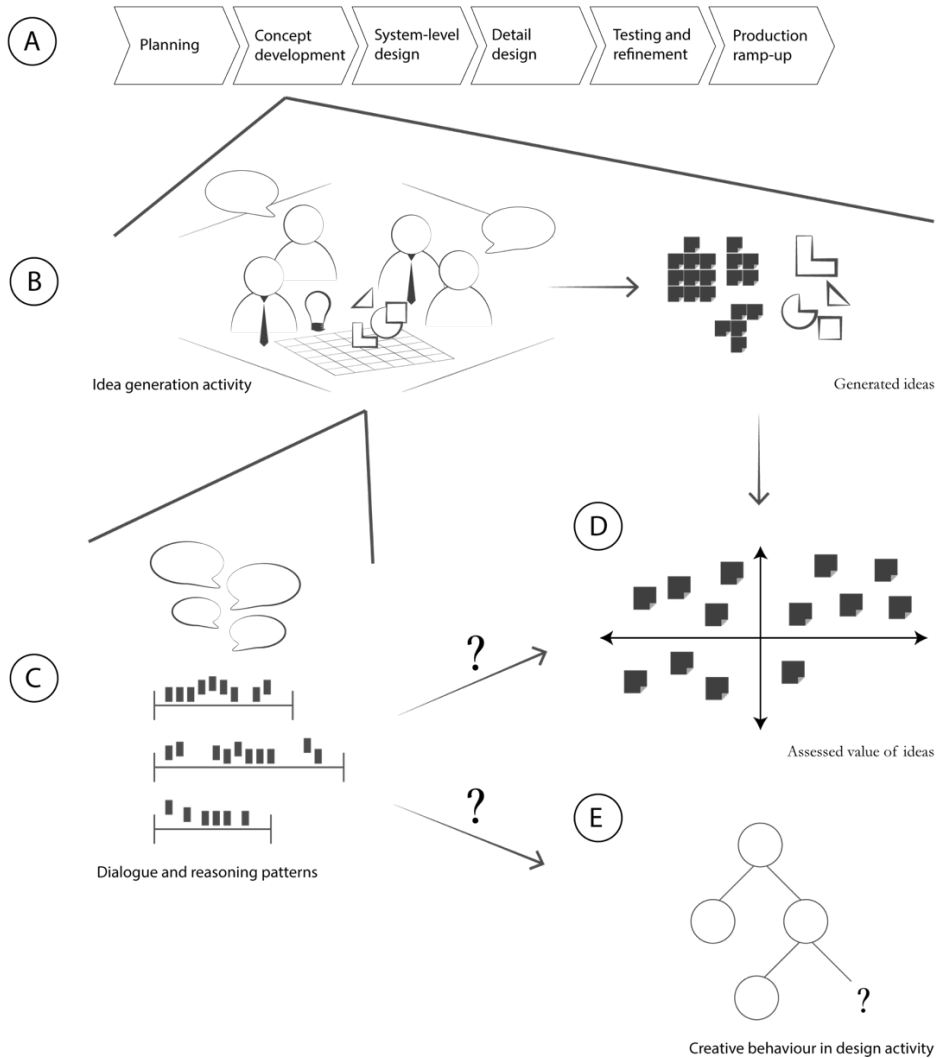
Figure 1: Illustration of how the thesis is situated in relation to product development processes and the aspects of design activity investigated. Point A is adapted from (Eppinger & Ulrich, 2011).

Figure 1 shows how the thesis investigates design activity:

A. Design follows broad stages from initial need to finished and marketed solutions (Eppinger & Ulrich, 2011). Of these, idea generation is decisive for the following stages in the design process.
B. Ideas are commonly generated in idea generation sessions involving teams of designers where early ideas are produced.
C. Analysing micro-level reasoning patterns as it occurs in dialogue is important to understanding and qualifying the reasoning of designers and to support design activity towards producing more valuable ideas.
D. The effect of reasoning patterns from idea generation dialogue is investigated in relation to the assessed value of ideas.
E. Further, the effect of reasoning patterns on the creative behaviour and problem solving approach in on-going idea generation sessions is investigated.

2.1.3 Aims of research

Formulated as aims, this research focuses on how reasoning can be identified and analysed empirically to provide a basis for better understanding design activity, specifically during the stages of idea generation. In particular, the research addresses:

How reasoning takes place between people engaged in design and how it can be captured empirically. To capture reasoning as it takes place, it is not possible to rely on methods that ask people to reflect on past or on-going activity. Instead, capturing the dialogue between people is necessary to capture reasoning in real time as it happens.

How reasoning correlates to – and predicts – creative behaviour. From the design and creative cognition research traditions, research shows and suggests certain behaviours that have creative value to design activity. Consequently, the research aims to use reasoning patterns to predict and explain the reasoning behaviour and to provide a foundation for developing methods to support the creative behaviour in design activity.

How reasoning affects the value of idea generation activity in groups working on actual design tasks. In extension of the above, and acknowledging that is it difficult to apply general measures for the outcome quality of ideas in an industrial context, the research seeks to investigate the value of generated ideas in terms of what reasoning patterns took place during the ideas' generation.

2.1.4   Example data

To contextualise terms and show the empirical data used in the research, Table 3 presents an example of the protocol data used. The left-hand side of the table shows the protocol data, including a row count, speaker ID and the utterance, segmented to word phrases. The right-hand side of the table shows the four coding schemes applied: A) The identification of *idea* and *idea aspects* B1) the coding of *reasoning* types at a *micro-level,* B2) the classification of *design moves* into either *breadth* or *depth* types and B3) the classification of *idea theme*. The example is presented to give in introduction to the data used for the research and will be explained at length throughout the thesis.

Protocol data			Coding steps			
Row	Speaker	Utterance	A	B1	B2	B3
1	A	Then I'm thinking, eh,	idea			
2	A	it could also be to offer bathing for the guests,	idea	abductive		
3	A	it could be…	idea			
4	A	Like, winter bathing for instance,	idea	abductive		
5	A	so every night at eight	idea	deductive		
6	A	You drive out…	idea	deductive	Breadth	Showering
7	A	And then there is something…	idea			

8	A	Then you can bathe in the ocean.	idea	deductive		
9	B	Instead of showering when they get home?	idea aspect			
10	A	But then make this spa-area	idea aspect	deductive		
11	A	that is water saving.	idea aspect	deductive		
12	A	Then you don't need to shower in the morning either.	idea aspect	deductive		
13	B	Haha, no.	idea aspect			
14	A	If [you use] ocean water for bathing…	idea aspect			
15	C	I actually think that's pretty cool.	idea aspect	inductive	Depth	Showering

Table 3: Example of the protocols used in the research, including dialogue and data coding.

Part of the collected data also included the later evaluation of value of ideas, such as the one shown above. This process is explained in section 4.5.2.

2.2   THESIS STRUCTURE

The thesis is structured in five chapters.

Chapter One reviews the theoretical framework and background acting as the backdrop for the research. The chapter synthesises the main issues addressed by the research.

Chapter Two discusses research approaches and presents the applied research methodology and design of the studies providing data for the research.

Chapter Three presents the results of the studies and accounts for the main findings of the research.

Chapter Four examines the findings in terms of the implications, limitations and further avenues of research.

Chapter Five presents the conclusion and summarises the results, contributions and implications of the research.

3   THEORY AND BACKGROUND

This chapter reviews existing work that serves as the foundation for the research. The chapter is divided into four parts. The first part introduces the concept of reasoning and provides an overview of how reasoning has been studied and conceptualised in the field of design, while the second part reviews models of design activity and problem-solving through the lens of the underlying reasoning to provide a structure with which to empirically study reasoning in design. The third part describes idea generation as a critical phase of design processes and reviews existing methods for evaluating the creativity and expected value to ongoing design processes. Finally, the fourth part synthesises insights from the literature review and describes the objectives of the research.

3.1   REASONING

This section introduces reasoning as a central aspect of the thinking, deliberation and argumentation that takes place not only in design activity, but also in our everyday lives. Throughout, the section presents examples of reasoning as proposed by the reviewed models and theories.

3.1.1   Formal reasoning

Reasoning is at the heart of design activity and determines how humans respond to situations in every aspects of their lives (Johnson-Laird, 2009). The reasoning of designers consists of trains of thought, including deliberation, arguing and making logical inferences, and is central to understanding and supporting design activity (Rittel, 1987).

Since the works of C. S. Peirce in the mid 20th century and earlier, logical reasoning has been formulated as being of either *deductive*, *inductive* or *abductive* types (Peirce, 1980). These reasoning types define three formally distinct ways of drawing conclusions from premises. That is, they describe how people make decisions and understand the world around them. While the three reasoning types reach conclusions from premises in different ways, they all rely on the reasoning being based on some external knowledge assumed to be correct or factual (but without the conclusion necessarily being so). The formal perspective on reasoning has had a heavy influence on

design models and theories that prescribe design activity and processes, as described later in the section. Below, the three reasoning types are defined.

Deductive reasoning is self-referencing as it allows for reaching a conclusion from the logical implication of two or more propositions asserted to be true (Magnani, 1995; March, 1976; Reichertz, 2010). Consequently, deduction is justificational in that the premises guarantee the truth of a conclusion (Schurz, 2007). Here is a theoretical example of deductive reasoning:

The weather is sunny. John only brings his umbrella when it rains, so he will not bring it today.

Inductive reasoning is the process of deriving plausible conclusions that go beyond the information in the premises (Johnson-Laird, 2009). Similar to deductive reasoning, inductive reasoning is self-referencing in that it infers concepts only from available data within a model or frame of reference (Magnani, 1995; Reichertz, 2010; Schurz, 2007). Unlike deductions, inductions do not produce guaranteed true results. Instead, inductive reasoning infers conclusions that go beyond available data. One theoretical example of inductive reasoning is as follows:

Upon having drawn five white marbles from the bag, Peter concludes that all the remaining marbles in the bag must be white.

Abductive reasoning, considered central to design (Roozenburg, 1993a), is a process of conjecture that yields the best (and simplest) explanation for a course of events. An abduction is the preliminary estimate that introduces plausible hypotheses and instructs where to first enquire by choosing the best candidate from among a multitude of possible explanations (Magnani, 1995; Schurz, 2007). Therefore, abductions are reductive in that they intentionally pursue one amongst other ways to proceed. Unlike inductions, abductions do not require one to draw conclusions from available data. Abductive reasoning differs from deductive and inductive reasoning in that abduction relies upon guessing and (sometimes unfounded) assumptions as the basis for reasoning, as seen in this theoretical example of abductive reasoning:

Lisa's fingerprints were on the gun that shot Michael. Lisa is suspected of firing the gun.

As the above three examples of the reasoning types show, the differences between the types arguably do not reside in fundamental differences in the phenomena described. For example, the deductive example shown *concluding* that John will not bring his umbrella today because it does not rain is taken for granted as the only explanation for the *result* of the umbrella not being brought. However, there could be a myriad of other reasons for this. In the inductive example, Peter's choice to believe that all remaining marbles in the bag are white because the first five are could also be a non-conclusion since more evidence (more, or all, marbles) would be required to draw a conclusion. Further, more evidence might reveal marbles in other colours, or even other objects. In the abductive example, Lisa is only *suspected* of firing the gun because her fingerprints are on it, hence abducing the immediate best possible explanation that Lisa *probably* did not have any reason to have put fingerprints on the gun with any other purpose than firing it to shoot Michael. Using deductive logic, the conclusion might have been that Lisa *definitely* held the gun to shoot Michael.

In all three examples, the reasoning types convey an attitude towards drawing conclusions from premises. That is, the reasoning types are chosen (albeit in a very simplified form) to warrant a conclusion based on very few observations or background information. When dealing with design activity, often described as a complex process that also involves trade-offs (Clausen & Yoshinaka, 2009), values (Stumpf & McDonnell, 2002) and intentions (Bucciarelli, 2002), the only safe conclusion seems to be that there are always implicit reasons guiding how conclusions are drawn. Hence, the reasons for applying either abductive and deductive reasoning relate to notions other than purely logical ones and are based on the accumulated experiences held by the person doing the reasoning, such as mental models used to understand certain situations.

Therefore, attitudes and beliefs are central to design and are important to explore as they influence decisions reflecting underlying assumptions, knowledge or even facts.

3.1.2 Reasoning in design
As alluded to in the introduction, research on reasoning in design has a history dating at least five decades.

Initiating the conceptualisation of reasoning in design by drawing on the works of Peirce and thus directly on the formal reasoning types, March (1976) suggests the Production-Deduction-Induction (PDI) model. The PDI model proposes a rational design process of iterative procedures characterised by three different types of reasoning. March views reasoning as a productive-deductive-inductive cycle as a necessary element of reasoning in design. First, a productive step composes something novel. It suggests that something may exist. Second, a deductive step decomposes and predicts performance characteristics of a design that emerges from analysis of the composition. It proves something must be true. Third, an inductive step makes an evaluation based on the accumulation of knowledge and the establishment of values evolving from the prior productive and deductive reasoning. It tests whether something actually is true. Hence, the PDI model proposes reasoning as a cycle that repeats but also assumes an external measure against which to optimise the reasoning (i.e., designed solution). Recently, the PDI model has been criticised for proposing design to explicitly concern generalisation through inductive reasoning (Koskela *et al.*, 2018) and to draw overtly from the abductive, deductive, and inductive reasoning cycles used in scientific discovery (Magnani, 2004). Hence, there is reason to question the validity of inductive reasoning having a specific role in design reasoning.

For Roozenburg and Dorst, the essence of reasoning in design is proposed to be an abductive activity moving from *function* to *form* (2011; 1993), that is, in the opposite 'direction' from the types of reasoning described above based on Peirce's definitions of the reasoning types. In cases of reasoning leading to innovation or new ideas (i.e., reasoning from a desired function towards an appropriate form), such reasoning is abductive and termed either *innoduction* (Roozenburg, 1995) or *abduction-2* (Dorst, 2011). This signifies a type of reasoning that moves from an aspired value or function towards a form, but without knowing either the working principle or form beforehand. This process is also described as a two-step abductive process that both invents a *form* (design object), a *way of use* and a *mode of action* to fulfil the desired *function* (Kroll & Koskela, 2015).

Deduction	Induction	Explanatory abduction	Innoduction
Premise $\quad$ $p \rightarrow q$	Premise $\quad$ q	Premise $\quad$ $p \rightarrow q$	Premise $\quad$ q
Premise $\quad$ p	Premise $\quad$ p	Premise $\quad$ q	
			Conclusion $\quad$ $p \rightarrow q$
Conclusion $\quad$ q	Conclusion $\quad$ $p \rightarrow q$	Conclusion $\quad$ p	Conclusion $\quad$ p

Figure 2: Reasoning types in a propositional logic notation. Adapted from Roozenburg (1993).

Figure 2 illustrates how the different reasoning types are proposed by Roozenburg to allow making inferences in design using a propositional logic notation. Here, inference refers to the action of arriving at conclusions from different premises. The result, q, is the intended (whether existing or not) outcome of design activity; the case, *p*, is an object – thing – that makes the result, q, possible given a certain rule, $p \rightarrow q$. Hence, the different reasoning types employ the three elements, result, case and rule, differently to move from premises to conclusion. To exemplify reasoning in design, Roozenburg uses the imagined first development of a kettle to boil water using a stove. The example is presented below following Roozenburg (1993; adapted by Kroll & Koskela, 2014):

As a premise, it is desired to make a small portion of water boil (result). It is concluded that placing water on a burner (case) for heating (rule) is one among many possible modes of action. On the premise that a burner can heat water (result), a kettle (case) to hold the water in place (rule) is one, among many possible, viable solutions.

The above example shows a conceptual and simplified instance of design reasoning that in form is similar to the previously presented example of abductive reasoning using the case of Lisa, Michael and the fingerprints on the gun. However, the above example of reasoning differs in that it concerns the type of planning behaviour that design activity addresses (Rittel & Webber, 1973) and therefore concerns a backward reasoning from an

outcome to the solutions that must be designed to realise the outcome. Originally, the example was termed *innoductive* by Roozenburg, since both a new *rule* (the use of a metal container to contain water over a burner) and the *case* (the kettle (container)) were invented in one inference. However, the more recent analysis of the example (Kroll & Koskela, 2015), as also shown in the example, divides the *innoductive* inference into two abductive inferences – also termed explanatory abductive in Figure 2. Both Roozenburg and Dorst on the one hand, and Kroll and Koskela on the other, agree that design reasoning must be abductive by definition since there are no other ways of proposing something new. However, as the differences in the examples show, it becomes a matter of framing a certain situation that decides how 'many' inferences are useful to explain design reasoning. To emphasise this difference, consider the following hypothetical examples of design reasoning using the above propositional notation.

In the case of deductive reasoning, a certain result is concluded from a known rule and case, for example:

An umbrella (case) can keep a person dry in rainy weather (result) because the umbrella is made of a water-repellent material (rule).

In contrast, to illustrate abduction, a case is concluded on the basis of an observed result and a known rule, for example:

Desiring a means to read in the dark (result) and knowing that electrifying a lightbulb creates light (rule), it is concluded to use a lamp (case).

As the above examples illustrate, the formal model for reasoning is highly limited and requires a multitude of assumptions being made or facts known (and taken for granted). To illustrate using the deductive example: It is assumed certain that the umbrella will keep the person dry, but this example does not consider that other factors might influence that ability to keep dry, such as wind blowing away the umbrella or making the rain come from multiple directions. Turning to the abductive example, before the invention of the lightbulb, a lamp to hold the bulb in a desirable position, and so on, the above example of abductive reasoning would be different and require many other inferences being made.

In the above definitions and examples, reasoning processes are conceptual and assume a logically sound reasoning pattern that simplifies situations and one in which abductive reasoning is the only reasoning type with the potential to create something new (Dorst, 2011; Roozenburg, 1993).

Shifting the perspective to models prescribing design activity, the activity is described as comprising stages that start by formulating initial hypotheses to propose desired functions, followed by the generation of probable behaviours and solutions to such functions, involving evaluation and reflection on whether these solutions are suitable for the desired function (March, 1976; Schön, 1991). Such processes involve both abductive, deductive and inductive reasoning and are iterative processes that do not follow strict abductive-deductive-inductive sequences (March, 1976). Despite the criticism of March's PDI model, it does provide a process-oriented perspective on design that suggests not only that design is reliant on abductive reasoning, but also that the process of design (reasoning) involves phases that are better described using other types of reasoning. In a study by Galle (1996a), empirically testing the PDI model with reference to the propositional notation by Roozenburg (refer to Figure 2), he proposes a different viewpoint on design reasoning. Galle introduced a replication protocol to force experts to rationalise and explain the work of others, and he primarily differed from the above by introducing varying degrees of 'absoluteness' to premises. Hence, the applied protocol analyses the generation of new concepts through:

a) The introduction of desirable, required and 'good' premises;
b) Establishing chains of reasoning that rely on conclusions made sequentially.

Hence, when empirically studying reasoning, the work by Galle demonstrates how premises are used in a more flexible way and that such premises permutate over sequences of reasoning. Galle concludes that it is possible to introduce new solutions using only deductive reasoning (made possible when premises are not definitive as per the formal logical definition) and finds that there is no empirical evidence for the inductive reasoning stage proposed by the PDI model (March, 1976).

To further this line of argumentation, Rittel (1987) describes design activity as a disorderly process that is inherently argumentative in its reasoning since design activity involves the negotiation between different perspectives and desires of those involved in a design process (Bucciarelli, 2002). Hence, design is understood as a social process through which solutions emerge as a result of argumentation between different perspectives and values of those involved in the process. In such processes, reasoning is reflected by the deliberation and debate between designers in which language plays a performative role by enacting and constituting design (Dong, 2007).

3.1.3   Informal reasoning

From an informal perspective, reasoning is described as being more dynamic and intentional (Binkley, 1995). One way to define such differences is through the notion of mental models that are the accumulation of knowledge, experience and resulting preferences held by individuals (Johnson-Laird, 1983). Observing that reasoning is non-monotonous, reasoning reflects the beliefs and values of the person, which is in contrast to the formal perspective offered by the Piercean perspective on reasoning. While the notion of informal reasoning has not been explicitly studied in a context of design, it has however been influential in theories and models of design activity reflected in ideas such as *design as argumentation* and performativity (Dong, 2007).

Per definition, the reasoning types of deduction, induction and abduction describe ways of making inferences from premises that reflect knowledge and beliefs held by the person engaged in reasoning (Dorst, 2011a). Such knowledge and beliefs form, and stem from, mental models (Johnson-Laird, 1983). Mental models are constructs that organise knowledge pertaining to specific contexts (Klimoski & Mohammed, 1994) and are thus relevant in the understanding of human behaviour and reasoning in design activity (Badke-Schaub *et al.*, 2007). Mental models are not fixed and change according to new experiences and knowledge created in relevant situations (Johnson-Laird, 2009). These mental models are simplified versions of reality that allow individuals to react to different situations depending on the models activated (whether consciously or unconsciously). Therefore, as logical reasoning is based on mental models, inferences drawn from reasoning are not fixed and vary between individuals. Hence, empirically studying

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reasoning implies that the reasoning observed reflects, and depends, on the individual mental models held.

Rittel (1987) defines reasoning in design as *a process of argumentation*. In design activity, this results in issues and competing positions that are interconnected and 'open' simultaneously, as a consequence of different mental models being enacted between those involved in design activity (Dong, Kleinsmann, & Deken, 2013). When engaged in a verbal discourse between those involved in design activity, these divergent perspectives can appear as speculation, argumentation, trade-offs or negotiation (Bucciarelli, 2002; Rittel, 1987). Furthermore, when reasoning in a context of dialogue with other people, the person uses mental models, implicitly or explicitly, to create a frame of understanding, which in turn allows the generation and description of solutions. As design is a social process (Bucciarelli, 2002), involving differing perspectives of those involved, ideas are not necessarily understood or accepted by the audience, resulting in an argumentative interaction between participants (Stumpf & McDonnell, 2002). Thus, the 'logic' of reasoning then takes the form of conclusions based on premises that both draw on existing understandings (facts) and on values (Stumpf & McDonnell, 2002) and thus diverge from the logical definitions of reasoning that assume a universal truth for deductive reasoning and a strict adherence to only what is observed for inductive reasoning (Peirce, 1980).

Taking the definition of reasoning in design as a *process of argumentation* at face value (Rittel, 1987), the field of argumentation theory and rhetoric offers insight into explaining reasoning between groups of people. Argumentation theory defines argumentation as an integral part of reasoning (Mercier & Sperber, 2011). Thus, analysing conversation between groups of people engaged in design holds the potential to help understand and explain *verbal reasoning* as the deployment of linguistic processes to satisfy the demands of reasoning (Polk & Newell, 1995). Such attempts at verbal reasoning derive their effectiveness from their similarity to the formal types of reasoning (Perelman & Olbrechts-Tyteca, 1973). Verbal reasoning is therefore not identical to the deductive, inductive or abductive reasoning types in the formal logical sense, but the characteristics of utterances share similarities with the reasoning types in their verbal deployment. Perelman and Olbrechts-Tyteca go on to express that "the choice of terms to express

the speaker's thought is rarely without significance to the argumentation" (ibid. pp: 149). This process of argumentation creates frames that persuade and change the perceptions and perspectives of all involved in a conversation. Hence, the use of reasoning to propose an idea, the *framing*, is important to guide design activity, providing a way to 'see' a problem or design issue (Schön, 1991). This is backed by the finding of Stumpf and McDonnell (2002) that framing potentially persuades and changes the perceptions and perspectives of those involved in a conversation. Likewise, the notion of primary generator also proposes that the way design activity is initiated has a distinct influence on how design activity develops (Darke, 1979). Using empirical analyses of dialogue between expert-novice architects, Darke found qualitative examples of how initial perspectives on landscape designs, or even abstract notions of curvature and fit to landscapes, would act as guidelines for the subsequent ideas and concepts developed. Hence, it is relevant to understand the early features of design reasoning.

3.1.4   Summary of theories and models of reasoning in design

The review of reasoning provided a basis for understanding how the three types of reasoning signify fundamentally different ways of making inferences. On the one hand are the formally derived and conceptual definitions of reasoning that primarily describe design activity, while on the other hand are examples of empirical analyses of design reasoning. As argued for in the introduction, there is a need for understanding micro-level reasoning to further understand design activity. What this means in particular is not clear from the original source (Rittel, 1987), but is here interpreted as the intention to apply an informal, argumentative perspective on reasoning. This entails drawing from empirical instantiations of reasoning between people; that is, verbal reasoning that occurs over the course of a dialogue between individuals.

Such *verbal reasoning* is not identical to the deductive, inductive or abductive reasoning types in the formal logical sense, but it is a verbal realisation much like the logical reasoning types in their verbal deployment (Dong, 2007). Hence, perceiving the dialogue of groups as a process of argumentation is representative of the underlying reasoning with the important implications that:

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a) The reasoning reflects the deployment of a mental model that might be different from the ones held by those addressed in verbal reasoning (Badke-Schaub *et al.*, 2007; Johnson-Laird, 1983).
b) The verbal enactment of such reasoning is influenced by values and beliefs and in turn acts to propose a certain perspective based on the experience, values and intentions of the individual doing the reasoning (Dong, 2007; Stumpf & McDonnell, 2002).

Verbal reasoning is similar to the formal types of reasoning presented earlier, but with the important difference that verbal reasoning is influenced by the above factors. Studying verbal reasoning entails acknowledging that not everything is made explicit and that the verbalised reasoning serves as an argument towards some goal that the person doing the reasoning wants to lead others to believe or accept. That is, design is here understood as a process of argumentation (Rittel, 1987). As such, it is relevant to broaden the perspective on reasoning in design to encompass models of design activity that to a higher degree attempt to describe the stages in thinking and reasoning that designers undergo to approach what might be conceived as the micro-level of design activity.

3.2 Models of design activity and problem-solving

This section reviews existing work within models of design activity and creative problem solving. These models provide a basis for understanding the micro-level activity of design in relation to the underlying reasoning.

3.2.1 Structuring approaches of design activity

Various models and frameworks emphasise design activity as a process involving different types of thinking and behaving. The following section reviews such models of design activity, focusing on descriptions or prescriptions of the micro-level steps and thinking involved in design activity.

PDI Model

The PDI model proposed by March, as also described earlier, presents a rational design process of iterative procedures characterised by three different types of reasoning. In this section, the model is presented again, only this time focusing on the proposed sequences of thinking (and reasoning) that the model ascribes to design activity. March proposes a productive-deductive-inductive cycle as a necessary element of reasoning in design. Empirically testing the PDI model, a study by Lloyd and Scott (1994) analysed think aloud protocols of engineering designers for generative, deductive and evaluative reasoning, finding that reasoning types interact and that generative-deductive-inductive sequences occur during design activity, but also identifying other sequences of reasoning. In a similar study, Galle (1996a) empirically analysed design reasoning through the use of replication protocol analysis by asking an expert architect to replicate the interpreted reasoning underlying other people's work. Using such analysis, he found patterns of inference corresponding to abductive and deductive reasoning and argued that deductive reasoning can be productive and introduce new elements to a design. He further observed that design reasoning is occasionally opportunistic and based on beliefs, and therefore does not necessarily reach a strict formal logical conclusion as per the premises acting as the basis for reasoning. He also did not find evidence for the inductive stage proposed by the PDI model.

Theory of reflective practice

In the theory of reflective practice, Schön (1991) proposes a perspective on design activity. Acknowledging that design contains logical design patterns consisting of "*if... then*" propositions that occur in cumulative sequences from prior decisions, Schön emphasises the different contextual norms drawn by the domains of different stakeholders involved in design. The process of design, from Schön's perspective, is a practice involving *naming*, *framing*, *moving* and *reflecting* steps in a cycle converging towards understanding the problem and moving towards a solution (Schön, 1991). First, naming focuses explicitly on a part of the design task. The second phase, framing, guides subsequent activity by providing a way for individuals and teams alike to 'see' and shape the design problem. Third, moving generates solutions to solve the problem set by the frame, and the fourth stage, reflecting, evaluates moves relating to their desirability. A study by Valkenburg and Dorst (1998) using protocol analysis found that a student design team managing both *framing* and *moving* activity in integration produced good team performance. This suggests that a dynamic between activities that diverges and allows new ways to 'see' a design task (framing) in combination with the generation of solutions to solve, or try out, the task is indicative of 'good' design activity, in the sense that design teams displaying this behaviour were more successful.

Generative sensing

Using the concept of generative sensing, Dong *et al.* (2016) describes design thinking as a pattern of deductive and abductive steps that provides different "ways through the problem" (ibid.: p 3) in the case of design concept evaluation. Aside from finding abductive reasoning present in evaluation, they also argued for abductive reasoning being directed towards both convergent and divergent thinking, proposing both new frames of understanding and as ways of reaching conclusions.

Dong *et al.* (2015) analysed verbal protocols of reasoning processes between people discussing and evaluating design ideas and concepts in terms of the deductive, inductive and abductive reasoning types. They showed that

reasoning can be consistently identified from verbal protocols of dialogue between groups of people. They found that the type of reasoning dominant when evaluating ideas influenced the evaluation of the ideas. Abductive reasoning for evaluating tended to result in more ideas being accepted, while the opposite was true for when deductive reasoning was used for evaluation. They argue for further debating and analysing empirical reasoning, as opposed to theoretical observations on reasoning in design from a logical perspective.

C-K theory

An alternative model of design has been proposed by Hatchuel and Weil (2008). The Concept-Knowledge (C-K) model emphasises the interplay between what is conjectured or unknown and what is known or in existence and describes operators between concept and knowledge. One such operator only exists between knowledge domains and thus consists of logical reasoning, where certain conclusions can be reached (akin to that proposed by Peirce). Other operators allow for making concepts and assessing them through available (accepted) knowledge or, conversely, to use knowledge to inform and generate new concepts. Finally, operators suggest interplay between concept spaces, where there is no necessary link to existing knowledge. This process is similar to that of using innoductive reasoning (Roozenburg, 1993a) or abductive-2 reasoning (Dorst, 2011), as described earlier, where non-determined premises are used for reaching a desired outcome. Overall, the C-K theory suggests a dynamic between ways of thinking that are tentative and that which is accepted, factual or otherwise taken for granted.

Problem-solving in design activity

Problem-solving theories and models of design emphasise that design thinking concerns (a) the notion of something novel and useful which is (b) concretised and explored and (c) evaluated to amend the original notion or concept (Gero & Kannengiesser, 2004). From the field of cognitive psychology, Johnson-Laird (2006: pp. 353) describes a generic problem solving cycle as the "use [of] some constraints to generate a putative solution, and other constraints, such as the goal of the problem, to criticise and amend the results". Christensen and Schunn [2009] studied the role of

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mental simulations in design from protocols of concurrent verbalisation of design teams. Mental simulations are reasoning processes in which new circumstances are envisioned and later 'run' as a simulation to determine whether such circumstances are useful to design activity. The study found that mental simulations reduce uncertainty about design activity and thus suggests they possess a productive attribute that is central to design activity being a process of reducing uncertainty towards solutions. In relation to reasoning, the use of mental simulations serves to run different mental models to ascertain their usefulness and in turn reason about a design task.

The reviewed models and studies of design activity all describe design activity as going through stages that enter into iterations or re-formulations towards a solution. Common to all models is the notion of sequences of activity that oscillate between activity that proposes a new perspective on a design task whether termed as compositions, frames, or ways to perceive on the one hand, and activity that seeks to describe, predict or move towards design solutions on the other. Thus, the approaches overlap in that they describe design activity as being iterative, involving cycles of reasoning towards solutions and as a process of learning about the problem through generating solutions, resulting in a co-evolution of problem and solution (Dorst & Cross, 2001). Such cycles are arguably similar to the characteristics of abductive and deductive reasoning respectively, while the role of inductive reasoning is more doubtful (Koskela *et al.*, 2018).

3.2.2   Creative problem-solving

Pertaining to the types of behaviour found to be indicative of creativity, the notions of *breadth* and *depth* moves have been subject to significant research.

The concepts of breadth and depth approaches in design activity have been used and studied widely to describe expertise and problem-solving activity in design (Ball & Ormerod, 1995; Visser, 1994). A review and discussion by Ball and Ormerod (1995) concludes that problem-solving approaches in practice are best perceived as deviating from singularly structured, top-down approaches, instead containing elements of 'opportunism', meaning that actual problem-solving activity follows a mix of breadth-first and depth-first modes (Ball *et al.*, 1997).

Empirical studies of breadth and depth approaches in design activity have studied differences between disciplines, for example between fields of expertise (Ahmed-Kristensen & Babar, 2012), educational background (Günther & Ehrlenspiel, 1999) or the balance between framing and detailing activities in a design task (Atman & Bursic, 1998; Atman *et al.*, 2005; Valkenburg & Dorst, 1998). The latter studies concerning the balancing between framing and detailing find that spending too much time on framing and problem definition results in weaker design solutions compared to focusing on generating detailing and alternative solutions.

The notions of breadth and depth moves assumes a design process relates to a specific *problem space* (Goel & Pirolli, 1992) in which different *moves* are taken to explore possible solutions. Expanding the definition of problem space allows for the perspective that problems and solutions co-evolve (Dorst & Cross, 2001), implying that design problems are hard to identify because they shift as part of design activity (Dorst, 2006). Under this assumption of design activity and problem-solving, breadth moves are akin to 'lateral' movements (for lateral thinking, see Bono, 1995) that re-focus the design task (Wiltschnig, Christensen, & Ball, 2013) or that propose new perspectives or solutions (Günther & Ehrlenspiel, 1999) without assuming that the breadth moves 'address' the same problem. In contrast to breadth moves, depth moves are then akin to linear moves that generate concrete solutions to a problem (Ahmed-Kristensen & Babar, 2012) or elaborate a specific solution from a set problem (Wiltschnig, Christensen, & Ball, 2013).

3.2.3   Summary of design activity models and theories

The review of models of design activity and problem solving shows that despite the relative agreement in the models that design activity recapitulates different types of behaviour, there are results showing that the underlying reasoning types in some cases function in discordance with their strictly formal definitions. For example, the arguments by Galle (1996a) propose that deductive reasoning does in some cases produce new solutions, or that abductive reasoning is also prevalent in the evaluation of design concepts (Dong *et al.*, 2016).

Similarly, the problem-solving approaches described by breadth and depth moves also contain examples of opportunistic behaviour noncompliant with

any modes of problem solving (Ball & Ormerod, 1995). Indeed, Rittel (1987) argues that there is no clear separation between problem definition, synthesis and evaluation in real-world design activity and that "only at the micro-level can we identify patterns of reasoning corresponding to [the design process]" (Rittel, 1987: p 3).

Hence, it is relevant to apply a micro-level analysis of reasoning to determine how design activity takes place from a micro-level reasoning perspective. Such an analysis could contribute to the understanding of how design activity actually unfolds and lay a foundation for new models of design as well as tools or methods for supporting design in practice. Analysing at a micro-level entails the use of research methods that allow for observing design *in-situ*, thus providing a supplementary tool to the methods that make inferences about design behaviour by qualitatively observing activity.

An empirical analysis of micro-level design activity can therefore also qualify and test the validity of the above models under the assumption that reasoning is representative of the various theoretical terms used to describe the stages of design activity.

3.3   IDEA GENERATION

This section describes the relevance of the idea generation stage in design processes and reviews existing work on the evaluation of design ideas and process.

3.3.1   Group idea generation in design

The idea generation stage of design activity is the basis for the further design of solutions to problems and as such unfolds a 'design space' that frames the continuing design process (Dorst & Cross, 2001). Idea generation is therefore key to creative processes (Cross, 2001) and for creating value through innovation (Björk, Boccardelli, & Magnusson, 2010). The early stages of design and idea generation designate an important part of the design process, one characterised by fewer decisions having been made and thus a greater openness to trade-offs and the exploration of new and creative ideas (Ahmed, Wallace, & Blessing, 2003). Thus, understanding design activity and behaviour at the idea generation stage is pertinent to understanding and supporting the overall design process.

In practice, idea generation often takes the form of short and delimited activities with participation from different disciplines and functions within organisations (Bucciarelli, 2002). In research, the value of idea generation is predominantly assessed using psychometric measures to quantify and characterise outcome ideas according to whether they are 'creative' (Runco & Jaeger, 2012) – that is, whether they are appropriate and useful and offer something novel compared to existing ideas and solutions (Sarkar & Chakrabarti, 2014). However, in design practice, the assessment is often less structured and tends to be based on process needs or strategic fit to organisations (Cooper, 1990; Cooper & Edgett, 2010).

Context of idea generation

While in practice group brainstorming is a popular method to generate ideas, experimental studies find that groups are less effective at idea generation and suffer a productivity loss (Mullen, Johnson, & Salas, 1991; Nijstad & Stroebe, 2006) compared to nominal (individual) brainstorming. Such productivity loss has multiple causes, including free riding or evaluation apprehension (Paulus & Dzindolet, 1993). However, positive effects from

group idea generation also exist in the form of cognitive stimulation that leads to additional associations or ideas compared to individual brainstorming (Paulus & Yang, 2000).

In industrial contexts, group idea generation processes are widely used and acknowledged as being central to starting any innovation process (Björk *et al.*, 2010) and to provide a way for combining different domains of knowledge and values (Bucciarelli, 2002). In such contexts, group idea generation serves not only to provide solutions to problems that represent individual knowledge domains, but also serves to generate solutions that span multiple domains of knowledge and thus provide a basis for ideas being understood and accepted across disciplines and departments of an organisation (Schön & Wiggins, 1992).

3.3.2   Assessing ideas

In contrast to idea generation, the assessment of ideas (i.e., their evaluation) constitutes an equally important part of creative thought, although it has been studied to a lesser extent (Blair & Mumford, 2007), and is therefore of importance to design activity. Most existing studies concerning the assessment of idea generation processes concern the use of psychometric measures (Kudrowitz & Wallace, 2012). Studies employing such measures for assessing ideas do so using mostly participants (typically student populations) working on artificial design tasks followed by ratings of products as part of controlled experiments and are therefore not representative of how idea assessment and selection processes occur in professional contexts.

A widespread approach to assessing idea generation processes deploys psychometric measures to evaluate outcome ideas individually (Kaufman & Sternberg, 2010), commonly asserting that that expert judges can ascertain the value of such ideas (Amabile, 1996). Measures commonly draw from similarities to the standard definition of creativity, which states that for something to be creative, it must be both original and useful (Runco & Jaeger, 2012). Hence, a multitude of studies exist that have used related measures such as novelty, usefulness and feasibility (Chulvi *et al.*, 2012; Kudrowitz & Wallace, 2012). Many such studies investigate differences between the evaluation of idea metrics according to factors such as

experience (Sarkar & Chakrabarti, 2014) or creative methods used (Howard, Dekoninck, & Culley, 2010; Linsey *et al.*, 2011; Shah, Kulkarni, & Vargas-Hernandez, 2000). The metrics used in these studies are less effective for a product development process, as using generic metrics does not cover the complexities for companies in defining appropriate criteria for idea assessment, which may be as challenging as selecting the best ideas (Onarheim & Christensen, 2012). The issue of using general measures for evaluating ideas is further underscored by the lack of formal processes for companies to handle idea assessment and selection (Barczak, Griffin, & Kahn, 2009). Hence, the study of idea assessment in practice entails studying lacking or non-systematic methods.

Pertaining to using psychometric evaluations of ideas to infer about the creative process directly, studies are limited. One study (Ward, 2008) found that practical ideas were negatively correlated to original ideas, and that ideas were less original when relying on specific within-domain knowledge, as opposed to not relying on specific domains. Sarkar and Chakrabarti (2014) found that ideas concerning higher levels of abstraction positively influence the novelty of outcomes, while lower levels of abstraction positively influence the usefulness of outcomes.

Aside from uncertainties related to criteria and processes for assessing ideas, studies report cognitive biases influencing evaluations. Blair and Mumford (2007) argue that risk averseness may play a role in the assessment of ideas, resulting in ideas perceived as risky being rejected, while ideas implementable in existing systems and within given time-frames are more likely to be accepted. Similarly, Licuanan, Dailey, and Mumford (2007) found that evaluating ideas is more difficult for highly original ideas as opposed to ideas of average or low originality. They argue for three cognitive mechanisms that govern such failures: a) focus on operative goals; b) frame evaluation using a baseline of past performance and; c) lack of information about key attributes of an (original) idea. Hence, the mechanisms have in common that uncertainty in relation to ideas results in bias against them as a consequence of a lack of understanding and resulting risk averseness, as well as a focus on direct implementation and operation, resulting in the favouring of ideas perceived as less risky and uncertain.

3.3.3   Assessing the creative process

Unlike evaluating outcome ideas as described above, assessing creativity concerns makes inferences to the likely outcome of idea generation through observing certain behaviours or identifying process indicators from actual design activity.

From a process perspective, Goldschmidt and Tatsa (Goldschmidt & Tatsa, 2005) argue that the links between specific occurrences in design activity are a valid means to gauge creativity, referring to the notion that "interesting creative processes almost never results from single steps, but rather from concatenations and articulation of a complex set of interrelated moves" (Gruber, 1980: pp. 177-178).

A common methodology for determining such creativity is the empirical study of links between moves in idea generation (Goldschmidt, 2014). Moves are delimited and recognisable instances of design activity. Goldschmidt (ibid.) defines creative behaviour as critical moves, measured as those moves or segments in a design process that are interlinked at a threshold defined by a specific analysis. In particular, moves that have links forward, and thus are used for idea generation later in the process, are responsible for the creative foundation in a design process (Goldschmidt & Weil, 1998). Figure 3 shows an example of how links occur between ideas, and also how certain are ideas are more connected than other ideas. van der Lugt (2001) found that ideas highly inter-linked in the idea generation process are perceived to be of higher quality. Yet, these studies do not proceed to evaluate the specific characteristics of such critical, or highly inter-linked, moves but rather, as opposed to the psychometric approaches described above, accept theoretical and empirical explanations as indicative of creative quality.
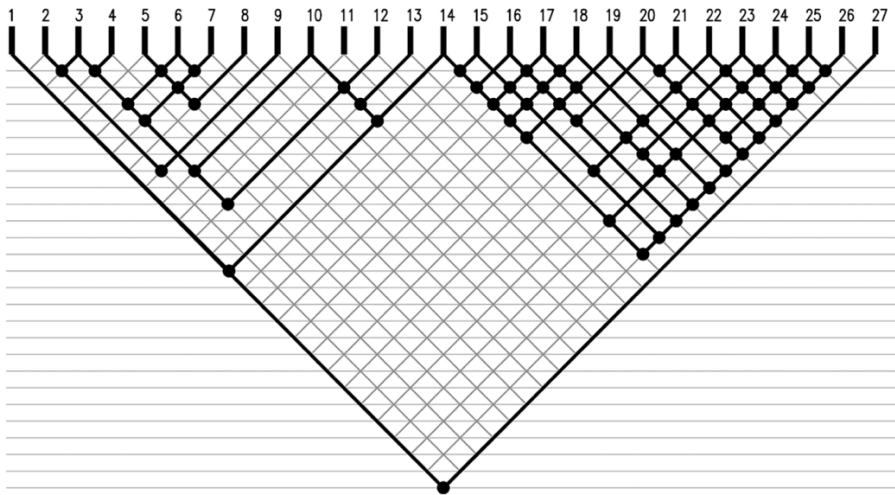
Figure 3: Links between ideas from an idea generation session - adapted from Goldschmidt (2014).

3.3.4　Reasoning and ideas

The use of idea generation activity to study reasoning patterns is founded in two primary arguments. The first states that the idea generation stage is critical to the continuing design process, as is also argued in Section 3.3.1. The second is that ideas in their structure form inferences similar to overall design activity. Dictionaries commonly define ideas as concerning: 1) An imagined outcome, 2) a course of action and 3) having a basis on something believed valid (Merriam-Webster; Oxford). Hence, perceiving ideas as a process of inference is consonant with the above descriptions of the reasoning processes underpinning design activity because the notion of an idea contains both a setting or proposition of an imagined outcome as well as a description of a more tangible solution. The early stage of idea generation provides a way to investigate the proposed abductive-deductive-inductive patterns because idea generation sessions usually span relatively short intervals, allowing for a greater number of episodes suitable for analysing patterns in reasoning.

3.3.5　Summary of idea generation in design

As the above review shows, there is a lack of methods to suit the needs of individual idea generation processes. Although the use of general metrics for

evaluating ideas might make sense from a theoretical perspective, it is rarely applicable to design in practice.

Other methods that focus solely on observing creative behaviour also lack the ability to measure whether such activity is actually valid for a specific context.

Consequently, there is a need for a means by which to evaluate ideas according to how valuable they are to actual design processes while also enabling insight into the process leading to such value. Hence, this research focuses on applying an understanding of the reasoning patterns occurring when ideas are actually generated with a measure of what degree of value such ideas are later determined to offer. This can provide a new way to monitor design activity and predict outcomes with the option to intervene and facilitate said processes in ways that are more likely to result in valuable ideas.

3.4 SYNTHESIS OF RESEARCH OBJECTIVES

Summarising the above, this section synthesises the reviewed literature to arrive at the objectives of this research. This project has four primary objectives, formulated as issues to be addressed:

1. Developing a method for analysing micro-level reasoning.
2. Identifying the patterns of reasoning that occur during idea generation.
3. Correlating reasoning patterns with creative behaviour in problem-solving activity in design.
4. Using reasoning patterns to predict the value of the generated ideas.

    1. Analysing micro-level reasoning in design

As the above review of existing research on reasoning in design shows, there has been little or no research to date on the reasoning patterns present at the micro-level of design activity comprising the inference made at the level of individual arguments between groups of designers. Further study is therefore desired to identify and understand reasoning patterns within arguments, which are defined in this study as micro-level design activity (Dong *et al.*, 2015; Rittel, 1987). The decision to analyse micro-level reasoning implies parting with the currently established perception of reasoning as containing both premises, rules and conclusions. The present approach allows for analysing patterns, while previous studies only determined a single type of reasoning, and thus allows the capture of the argumentative aspect of reasoning in design. Arguably, this allows for a more fine-grained understanding of how design activity takes place.

    2. Determining the patterns of reasoning taking place during idea generation

The research proposes to empirically test whether the characteristics of design activity display a pattern of activity that is identifiable through reasoning. Departing from the earlier-described formal definitions of abductive, deductive and inductive reasoning as distinct types and combining them with reviewed models of design activity, a process of reasoning in design would involve: 1) abductive reasoning that leads to a

problem setting through framing and by suggesting functions, followed by 2) deductive reasoning that concretises the solution and predicts its effects on the problem set, and finally inductive reasoning taking a more contended role in design activity. This process is expected to be found in design activity, although not necessarily strictly adhered to given the findings suggesting that design is also disorderly (Rittel, 1987)and opportunistic (Ball & Ormerod, 1995).

3. Correlating reasoning patterns with creative behaviour in problem-solving activity in design

From the perspective of creative problem-solving in design activity, the research proposes to correlate reasoning patterns with the notion of breadth and depth moves and to further aggregate this analysis to analyse the interrelation and accumulation of design moves. This has two purposes. The first is to develop a method for empirically analysing problem-solving strategies through reasoning patterns to understand the underlying cognitive activity (i.e., determining the short-term relationship within individual ideas between problem solving behaviour and reasoning patterns). The second is to determine whether there is a correlation between problem-solving strategies and the creative behaviour indicated by the interrelation of design moves (Gruber, 1980), or determining the longer-term relationship of how reasoning patterns influence later idea generation and problem-solving behaviour.

4. Using reasoning patterns to predict the value of generated ideas

Finally, there is a need for developing methods to evaluate the value of the generated ideas to the continuing design process. The research therefore focuses on correlating the analysis of reasoning patterns with the value of generated ideas to provide a way of monitoring idea generation processes and predicting their outcome value. Such insights into the effects of reasoning patterns on both problem-solving behaviour and the evaluated value of ideas can provide the foundation for developing tools and methods to diagnose and support design activity with the aim of improving design team performance.

3.4.1 Possible outcomes of the research

Addressing the above issues emphasises reasoning patterns as a critical element in design activity and explores reasoning in relation to both process- and outcome-related aspects in design.

For research in design, this study aims to provide insight into reasoning patterns as explications of the underlying cognitive processes in design teams to identify common assumptions, uncertainties or pitfalls in design activity that can be amended through further research. Such insights can be used to develop new models of design activity.

For design practice, the understanding of reasoning patterns can provide the foundation for methods, tools or techniques to monitor, diagnose and intervene in design activity to promote desired behaviour and achieve better outcomes.

For education, this research can provide an understanding of the fundamental patterns of inference taking place in design activity to teach students about inferences and how idea generation activity draws on a range of explicit and implicit intentions, values and existing knowledge.

4 RESEARCH APPROACH

This chapter describes the research methodology and approach taken to address the issues and questions raised from the review of existing work within reasoning in design and how it influences design activity.

The chapter is divided into four sections. First, the need for data and methods is considered in response to the literature review in the previous chapter. Second, the research approach is presented to give an overview of the appropriate data and methods. Third, the two studies conducted as part of the research are presented, including data collection and data analysis methods, and finally the limitations of the chosen methodology are described and discussed.

4.1 METHODOLOGICAL NEEDS AND CONSIDERATIONS

Certain methodological needs arise when the earlier research issues are addressed.

In order to understand design activity through analysing micro-level reasoning patterns, it is necessary to:

- Reliably identify reasoning patterns from the dialogue occurring between people in a design team during design activity.
- Be able to interpret what the reasoning patterns reveal about design activity.

To address verbal reasoning in design activity, the applied methodology and analysis need to acknowledge that:

- Verbal reasoning is non-monotonous and informal, and as such is not the same as formal logical reasoning.
- Reasoning occurs as a process of argumentation, and such arguments carry a performative aspect that not only responds to certain premises (or earlier reasoning) but has agency and influences future reasoning.

To understand the correlation between reasoning patterns and problem-solving activity, there is a need to:

- Analyse problem-solving behaviour from the same dialogue in which the reasoning patterns are identified.
- To reliably determine how problem-solving activity (in idea generation) evolves through different stages of lateral and vertical movements in a design space that is emergent.

To determine the influence of reasoning patterns on idea value, outcome measures need to:

- Be based on a method for evaluating ideas that is valid and representative of design activity in practice.
- Be able to reliably trace how a certain part of a dialogue led to an idea.

4.2 DATA AND METHODS

This section describes the data and methods appropriate for addressing the above-described needs of the research. The section is structured by presenting the type of data and methods necessary and is divided into four parts. First, the implications and process for conducting empirical, descriptive studies in design research are presented. Second, the section discusses the use of methods to analyse empirical data, followed by considerations for the use of methods for evaluating ideas. Lastly, the section is summarised and an overview of the applicable methods for addressing the research issues is offered.

4.2.1 Empirical studies

Conducting empirical studies in design research provides a basis for understanding activity as it actually takes place and captures the complexities of design activity not accessible through purely experimental study designs or other methods that rely on indirect data to describe phenomena (Blessing & Chakrabarti, 2009).

A profound drawback of using empirical data is related to the difficulty of recruiting representative participants, as well as the challenges in gaining access to the kind of activity necessary to address research questions (Ahmed, 2007).

To capture valid data, Frankfort-Nachmias and Nachmias (1996) describe three types of bias to avoid:

1. *Demand characteristic:* Participants behaving differently than they would otherwise because of the study design.
2. *Experimenter bias:* Unintentional communication of expectations from the researcher to participants.
3. *Measurement artefact bias:* The researcher reveals the study aims, hypothesis, or other aspects of the study.

Hence, all three biases must be avoided to ensure valid data when collecting data from real-life activity, as is desired here.

4.2.2 Representative data from design practice

With the intention of the research to focus on an empirical analysis of design as it takes place, it is important to include both experienced participants and cases from industry to ensure representative data.

Pertaining to participants, the use of experienced practitioners, such as people working in industry, allows for a better understanding of design activity compared to the commonly used student participants (see e.g., Linsey *et al.*, 2011b; Shah *et al.*, 2000). A study by Ahmed *et al.* (2003) found differences in reasoning activities between novice and experienced designers, warranting data collection focusing on design activity of experienced professionals, since this group is more representative of actual design activity and behaviour than novices or students. Such experienced practitioners provide access to skills, knowledge and competencies that are otherwise not possible using student participants (Ahmed & Christensen, 2007). Using practitioner participants also provides the benefit of more accurately capturing the social and value-based aspects of design activity, as these factors play an equally important role in the pure domain-specific knowledge held by participants in a design process (Atman et al., 2005; Bucciarelli, 2002).

To facilitate, and simulate, the above dynamics, skills and knowledge, the use of cases from real-life industrial contexts is important to provide a naturalistic setting (Christensen, 2009) that addresses the *demand characteristic* bias described above.

4.2.3 Methods for empirical data

Methods for capturing empirical data in design research are plentiful and include interviews, case studies, ethnographic methods (Ball & Ormerod, 2000), observations (Ahmed, 2007) and protocol analysis (Ericsson & Simon, 1993).

Given the aim of the present research to analyse micro-level design activity, methods such as interviews, case studies and relying solely on observations are not feasible. Hence, the focus needs to be on methods that allow the analysis of continuous data in a real-life context to avoid confounding a study by leading participants to behave differently than they otherwise would (*demand characteristic* bias described in section 4.2.1). Hence, both

ethnographic methods and protocol analysis are potentially relevant methods for collecting and analysing data.

4.2.3.1 Ethnographic methods

When seeking to empirically understand reasoning taking place in design activity, there is a need for collecting and reliably analysing 'messy' data that involves social as well as technical aspects (Lloyd & Deasley, 1998). One approach to such analyses is through observational methods often used in ethnography to gain rich and interpretive data that embraces the subjectivity of doing research (Ahmed, 2007). One approach from the field of design research, termed *applied ethnography* (Ball & Ormerod, 2000), differs from traditional ethnography in that:

- It has an *a priori* independence from previous models and theories is less pronounced than in traditional ethnography and is therefore open to what data shows rather than solely relying on prescribed models and theories.
- It focuses on short, intensive observations, resulting in the risk of not capturing otherwise relevant data.
- The requirement for verification and objectivity in ethnography is less of a focus as applied ethnography defines *a priori* contexts for conducting research.

Hence, while ethnography affords rich data, it also presents an issue when desiring to investigate a specific phenomenon – in this case reasoning patterns. Yet, the above characteristics of applied ethnography are important to acknowledge in research when aiming to capture empirical data representative of practice.

4.2.3.2 Protocol analysis

The use of protocol analysis is widespread in design research and used in various forms in many of the earlier-reviewed studies of design activity and reasoning (Dong *et al.*, 2015; Galle, 1996b; Lloyd & Scott, 1994). Protocol analysis concerns the rigorous analysis of data, often in a transcribed form that is subject to coding or other forms of classification (Ericsson & Simon, 1993). A popular approach to protocol analysis is the use of the think-aloud protocol in which participants explain activity as it is done, often used in design and cognitive science to address research questions related to the

cognitive underpinnings of action (Christensen, 2009). However, think-aloud protocols are not suitable for concurrently capturing dialogue between people, as they would completely break out of the dialogue.

Protocol analysis often applies quantitative analyses that can provide generalisable and replicable results that are more objective than ethnographic methods (Chi, 1997). Further, protocol analysis also allows the application of qualitative analyses; indeed, it is based on such for defining elements such as coding schemes (ibid.) making the method, if applied using a suitable study design, potent for analyses requiring the observation of more general patterns in data in combination with rich analyses of specific data.

Both ethnographic methods and protocol analysis are time-consuming. However, the shortcomings outweigh the advantages when it comes to the granularity and level of details afforded by the method, such as the abovementioned combination of describing general patterns in data and specific qualitative observations. As both methods are markedly different in their strengths, assumptions and approaches to producing results, there is a need for finding a middle ground that allows capturing replicable data while also ensuring answering 'the right questions' via a data-driven, qualitative component.

4.2.3.3 Quantifying qualitative analyses of verbal data

An approach to analysing verbal data seeking to combine the tenets of quantitative and qualitative methods has been proposed by Chi (ibid.). Chi provides a practical framework for such an endeavour, outlining four methods of integrating quantitative and qualitative methods.

1. The use of qualitative data to interpret quantitative results when the focus is predominantly on the quantitative results, but using qualitative analysis to better interpret and understand the results.
2. A complementary approach using both quantitative and qualitative measures to support each other and to use qualitative analysis to generate inferences for quantitative analysis.
3. Using qualitative analysis to generate hypotheses that can be subject to quantitative analysis.

4. Employing qualitative data to quantify the analysis, paving the way for quantitative analysis, such as through qualitative coding.

Hence, the framework by Chi suggests different approaches to combine quantitative and qualitative methods in order to harness the advantages of the different types and offer the best possible answer to the research questions pursued.

4.2.3.4   *Verbal analysis*

Chi continues on to offer a specific method – verbal analysis – as a combination of protocol analysis and qualitative analysis. The method differs from protocol analysis (as defined by Ericsson & Simon, 1993) in three ways:

1. The focus of verbal analysis is on concurrent verbalisation instead of think-aloud verbalisation.
2. Protocol analysis primarily focuses on testing and validating starting with an ideal model of a task or activity, while verbal analysis does not create an *a priori* model but rather focuses on explaining what takes place.
3. The methods of validation are different. Where protocol analysis validates through 'degrees' of agreement or adherence to predetermined factors, verbal analysis validates through statistical tests to determine whether hypotheses are supported.

Chi's verbal analysis method will be used and described in detail in later sections.

4.2.4   Value of generated ideas

As described in Section 3.3.3, there is a lack of systematic methods for assessing ideas (Barczak *et al.*, 2009). To evaluate the value of ideas generated from the process, a practice-based approach will be applied. This method relies on contextualising ideas according to organisational interests and on-going development projects and situating the idea assessment according to the development process (Cooper & Edgett, 2010). This will allow for analysing each idea, not according to generic psychometric measures (Sarkar & Chakrabarti, 2011) or external assessments (Amabile, 1996), but rather determining the specific value of ideas according to present criteria and process needs (Cooper, 1990).

4.2.5   Summary of methods applied

As the above review of methods for analysing design activity shows, an appropriate method is to apply an adapted verbal analysis to code the following aspects of design activity:

- **Ideas generated**, to identify ideas generated in group design activity.
- **Reasoning patterns**, to provide a basis for understanding verbal reasoning patterns in design activity.
- **Breadth and depth moves**, to distinguish how the problem-solving behaviour occurs when ideas are generated.

Further, to make inferences about the effects of creative behaviour in design activity, the following aspects are analysed:

- **Links between ideas**, to determine the interrelation and accumulation of ideas as an indicator of creativity.
- **Practice-based evaluation of ideas**, to rate ideas according to their quality.

The specific approach for coding and analysing the above aspects is described for each study in Section 4.4.1.

4.3 STUDIES

This section presents the studies conducted as part of the research. Two studies were completed, both applying the same coding scheme for generated ideas and reasoning, but differing in the analyses of how reasoning patterns relate to design activity. Hence, the reasoning patterns are used as a continuous analysis method, while the studies are used to investigate the prospect of using reasoning patterns to explain design activity.

Protocol analysis of concurrent verbalisation was used and deemed appropriate to understanding underlying cognitive processes, such as reasoning, with minimal interruption of the recorded process (Ericsson & Simon, 1993). Consequently, verbal protocol analyses of practitioners from industry are relevant and expected to be highly representative of design cognition found in practice (Ahmed *et al.*, 2003; Chi, 1997; Christensen & Ball, 2014). As the activity was in groups, no forced or primed instructions for the participants to think aloud were given, resulting in a minimum of interference with thought processes to avoid participant bias (Frankfort-Nachmias & Nachmias, 1996).

Study 1 – WORKZ – consists of the recorded idea generation session covering 5 groups of experienced participants working on an industry case. The participants took part in the study in the context of an innovation workshop and were thus not familiar with one another beforehand.

Study 2 – SMART – consists of the recorded group idea generation sessions, and later idea evaluation, of 4 companies working on product development projects. The recorded sessions were part of a product innovation process; therefore, the groups were familiar with each other.

Study 1 was completed and analysed first, after which new questions arising from that study were addressed in Study 2. Hence, after the description of Study 1, the methodological findings were used in the design of Study 2.

4.3.1 Overview of studies

The studies are described in detail in the following section, and their characteristics are summarised in Table 4.

Study	Study 1 - WORKZ	Study 2 - SMART
Environment	Experimental / industry case	Real-life product development
Data collection methods	Protocols containing: a) Video and audio recordings b) Verbal data c) Idea generation activity d) Evaluation of ideas	Protocols containing: a) Video and audio recordings b) Verbal data c) Idea generation activity from on-going development project d) Practice-based evaluation of ideas
Participants	Experienced practitioners from various industrial sectors	Industry practitioners spanning multiple disciplines
Number of cases	5 groups	4 company groups
Total number of participants	15	31
Time constraints	Yes	Yes
Duration	Three 20-minute intervals	Between three and five 30-minute intervals
Role of researcher	Absent	Facilitator
Type of design task	Innovation competition	New generation product
Topic	Design task derived from industry need – same for all groups	On-going product development project in 4 different product areas

Table 4: Comparing the central attributes and characteristics of the two studies.

Each study was designed to address different research issues. Table 5 shows the research issues addressed and methods used for each study. The only continuous analysis method was the coding scheme to identify ideas

generated and reasoning patterns, while the other research issues were explicitly addressed separately in the two studies.

Research issue	Data	Method	Analysis
Establishing a method for analysing micro-level reasoning in design	Video and audio recordings Transcribed verbal data protocols	Coding scheme for capturing ideas generated Coding scheme for capturing:	Inter-rater reliability check of coding schemes
Determining the patterns of reasoning taking place during idea generation	Idea generation activity Experienced participants Industry-based design task	a) Reasoning types using propositional logic b) Micro-level reasoning	Statistical test to quantify reasoning patterns Qualitative observations to interpret and discuss
Correlating reasoning patterns with creative behaviour in problem-solving activity in design		Coding scheme for capturing breadth and depth moves Determining links between ideas	Inter-rater reliability check of coding scheme and idea linkages Statistical test to quantify breadth and depth moves Qualitative observations to interpret and discuss
Using reasoning patterns to predict the value ideas generated	Registration of evaluation of ideas using practice-based method	Linking idea evaluation to coded protocols	Statistical test to quantify Qualitative observations to interpret and discuss

Table 5: Overview of research issues and corresponding need for data, research methods and analysis coloured per the distribution of studies: White fields for study 1, light grey for study 2, and dark grey for both studies.

Next, the two studies are presented in detail.

4.4 STUDY 1 – WORKZ

The study was conducted in the context of an innovation workshop offered by the company Workz to those interested in participating given their previous experience with design. The author designed the idea generation sessions to include a fictional, but realistic, design task, provided by a large Danish pump manufacturer. Participants were randomly assigned to groups led by student facilitators. It was in this context that the idea generation activity data used in the study was collected.

Overall, the study addresses the research issues of:

1. **Analysing micro-level reasoning in design** through the development of a coding scheme for reliably identifying reasoning patterns from concurrent verbalisations.
2. **Determining the patterns of reasoning taking place during idea generation** through analysing both the quantitative reasoning patterns and the possible qualitative observations from groups engaged in idea generation.
3. **Correlating reasoning patterns to creative behaviour in problem-solving activity in design** through investigating the correlation between reasoning patterns and problem-solving behaviour.

Determining the patterns of reasoning taking place during idea generation

The research issue concerns an analysis of the proportional distribution of reasoning within design ideas as a unit of analysis, divided into three parts. The specific division into three parts is grounded in the prevalence of models of design activity that concern two or more stages of design. While the greatest agreement between these is that of abductive-deductive patterns, as discussed above, there is some disagreement as to the role of evaluation in design activity. Hence, a three-part division of ideas will allow for a greater resolution for analysing reasoning occurrences as ideas develop and also leave room for investigating whether any unexpected patterns of reasoning occur at the end of generated ideas.

From the reviewed models of design activity, the following patterns are expected, of which Points 1 and 2 below are explored through hypotheses:

- The first step, abductive reasoning, states an intention or desired result by conjecturing that a specific aspect of the design task is relevant.
- Next, the middle part of deductive reasoning indicates the concretisation of solutions framed by the initial hypothesis.
- Finally, the last part poses a more tentative and exploratory question as to the role of inductive reasoning. While not expected to be prominent in idea generation given its evaluative nature (de Bono, 1995), there is an expectation that any inductive reasoning present will be more pronounced in the last part of ideas. Because this phase is contested in models of design reasoning (Koskela *et al.*, 2018), no hypotheses about what kind of reasoning is more prevalent in the last parts of ideas is proposed.

Together, the patterns predict that design reasoning follows an abductive-deductive pattern through two stages within each idea episode. As argued earlier in Section 3.3.4, ideas represent an instantiation of design activity, thus allowing the use of individual idea episodes as a basis for determining reasoning patterns through the proposed two-stage process within a limited timeframe. Rittel (1987) proposes that the reasoning patterns in design activity are disorderly. Thus, the hypotheses do not predict a strict adherence to an abductive-deductive pattern, but rather predict that each reasoning type is concentrated in specific parts of an idea.

HS1a states that:

Abductive reasoning (compared to deductive and inductive) is relatively concentrated in the first part of the verbal realisation of an idea.

HS1b states that:

Deductive reasoning (compared to abductive and inductive) is relatively concentrated in the middle part of the verbal realisation of an idea.

In addition to testing the hypotheses, a qualitative analysis of reasoning patterns found in the protocols was conducted to flesh out the implications of the quantitative analysis.

Correlating reasoning patterns with creative behaviour in problem-solving activity in design

To determine the correlation between reasoning patterns and creative behaviour, a coding scheme for identifying breadth and depth moves in idea generation in combination with a method to determine links between ideas was developed. The results were achieved through a combination of statistical tests and qualitative interpretations. The quantitative analyses, on which the hypotheses are based, predict *variations* in reasoning patterns from the abovementioned abductive-deductive patterns that were expected to correlate with design activity in two ways, formulated as two sets of hypotheses: a) to describe a short-term effect of how idea episodes develop through breadth and depth moves; b) to describe longer-term effects on how links between ideas occur.

The first set of two hypotheses investigated how reasoning patterns involving abductive and deductive reasoning influence breadth and depth moves in a context of design idea generation. That is, they assessed for any short-term correlation between reasoning patterns and problem-solving behaviour.

Pertaining to the importance of moves made early in design activity, the concept of *framing* (Schön & Wiggins, 1992) is understood as ways to 'see' a design problem, or the related notion of *primary generators* in the design process that serve as guiding principles of how to approach a design task (Darke, 1979). Empirical analyses of design activity have found that framing potentially persuades and changes the perceptions and perspectives of those involved in group-based design activity (Stumpf & McDonnell, 2002). An analysis would allow for predictions about the specific behaviour found in such *initial* moves, the moves introducing a new theme that potentially leads to an accumulation of interrelated moves indicative of creative interest (Gruber, 1980). Hence, it was expected that such reasoning types would *enact* the design and thus have a performative effect (Dong, 2007). Given the review of existing work in the field, it was predicted that abductive reasoning used as a framing in the very beginning of design moves would be associated with the proposal of a new frame of reference (Stumpf & McDonnell, 2002), whereas deductive reasoning would be associated with

proving or showing a solution in a set composition (March, 1976). **HS1c** states that:

Design moves started by abductive reasoning are more likely to be breadth moves than those initiated by deductive reasoning.

The literature indicates that abductive-deductive reasoning patterns are fundamental to design activity (Roozenburg & Cross, 1991) and that breadth moves are associated with framing and identifying design purposes *(Atman et al.*, 2005; Schön, 1991). Conversely, depth moves are more linear and restricted in their framing, seeking rather to predict or produce a solution (Fann, 1970; March, 1976), which is associated with pure deductive reasoning and thus not necessarily containing abductive reasoning. **HS1d** states that:

Moves containing abductive-deductive interactions are more likely to be breadth moves than those with no such interactions.

Predictions about creative behaviour and its influence on continued idea generation activity

The second set of three hypotheses investigates the influence of creative behaviours in the beginning of themes that become influential on creativity in the idea generation process. This set addresses a longer-term correlation between reasoning patterns and problem-solving behaviour.

In extension of the previous hypotheses, it is predicted that both abductive reasoning to start moves and the presence of abductive-deductive interactions are indicative of moves being more likely to serve as the basis of a theme that becomes more prevalent than those moves started by deductive reasoning or without abductive-deductive interactions. Thus, the reasoning pattern variables are assumed to share direction across the hypotheses relating to breadth and depth moves on the one hand and the degree of interrelatedness resulting from initial moves on the other. **HS1e** states that:

Initial moves started by abductive reasoning result in the theme being more prevalent than moves begun using deductive reasoning.

HS1f states that:

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Initial moves containing abductive-deductive interactions result in the theme being more prevalent than moves with no interactions.

Finally, studies indicate that finding a balance between framing and solution-generating activity leads to higher-quality outcomes (Atman *et al.*, 2005; Valkenburg & Dorst, 1998). This is congruent with studies showing that highly linked design moves are indicative of creativity and thus quality (Goldschmidt & Tatsa, 2005; Lugt, 2003). Thus, this study assumed that a higher number of depth moves following an initial theme, interpreted here as detailing, would lead to the theme becoming more prevalent in the latter stages of the idea generation process. **HS1g** states that:

As the number of depth moves following an initial move increases, so will the prevalence of the introduced theme increase.

4.4.1   Study description

The study was designed for groups of participants from industry engaged in idea generation for a specific design task. Participants were from different companies and industry sectors, and nine participants were female and six were male. Table 6 summarises the demographics of the participants.

Participant demographics					Previous work experience		
Partici pant	Group	Gender	Industry sector	Years of experience	Problem solving	Technical design	Creative methods
1	1	M	Energy	27	X	X	X
2	1	F	Higher education	7	X		X
3	1	F	Telecommunic ation	41	X		X
4	2	M	Logistics	20	X	X	X
5	2	F	Finance	19	X		X
6	2	F	Publishing	25	X		X
7	3	F	Graphic design	1	X	X	X
8	3	M	Publishing	35	X		X
9	3	M	Logistics	40	X		X
10	4	F	Higher education	10			X
11	4	F	Public administration	17	X	X	X
12	4	M	Organisation	15	X		X
13	5	M	Healthcare	23	X		X
14	5	F	Pharma	20	X		X
15	5	F	Insurance	14	X		X
				Average = 20.9 [SD = 11.5]	93%	27%	100%

Table 6: Demographics of participants from Study 1 – WORKZ.

Regarding the number of participants in the analysis, the argument is twofold. First, obtaining a high number of industry professionals as

participants is challenging, yet for the reasons outlined earlier, is preferable to using students, and second, the data segmentation and qualitative coding method is time-consuming and would be unmanageable with a larger sample.

The experience of the participants was on average high (20.9 years, refer to Table 6), but there were two participants with less than 10 years of experience. The later analysis of the results takes this into account.

4.4.2 Procedure

The participants took part in the study on a voluntary basis as part of a workshop in a parallel track of a larger conference hosted by an innovation consultancy.

Prior to the idea generation session, the participants were notified that they were being recorded as part of a research project.

The participants were introduced to the design task via a 10-minute presentation of the design task by a company representative from the company providing the case: *To create concepts for ways of radically saving water at a Copenhagen-based hotel.*

To make the design task understandable for participants of varying backgrounds, the task focused on the generation of ideas for radically reducing water consumption at a local hotel and could include ideas concerning technical solutions as well as organisational or behavioural ideas, or combinations thereof. The task was formulated prior to the experiment by an industry company with a commercial interest in the subject matter of the task to ensure relevance to real-life industrial design practice. No study participants were associated with this company.

Next, teams were generated at random to form five teams of three participants each. The teams were each provided with a separate room for the idea generation and welcomed by a student facilitator. The facilitators were graduate students of design engineering and guided each team throughout the session by instructing participants to a) allow individual idea generation but ensure that ideas are presented and discussed as a group; b) build on the ideas generated by others if relevant; and c) to ensure timekeeping. The facilitators were blind to the hypotheses and aims of the

study and followed a printed protocol to ensure that the teams adhered to the time schedule and activities. In some instances, the facilitator contributed to the discussion to make sure the teams did not become stuck when generating ideas. Since the facilitators were blind to the purpose of the study, their involvement did not interfere with the natural dialogue occurring in the teams.

Each team started with a 10-minute period to become familiar with the design task and the idea generation process. This period involved discussions between facilitators and participants regarding practical details as well as informal chats and socialisation in the teams. After this, the teams generated ideas for 20 minutes using the three creative methods: brainstorming, random images and bio-cards. The idea generation methods were intended to create variation over the course of the idea generation sessions. Participants were provided with paper for taking notes or sketching. Table 7 presents the creative methods used for idea generation.

Method	Idea generation with no instructions	Random images	Bio-cards
Description	Teams were instructed to brainstorm together to generate ideas, following the principles of generating many ideas and withholding criticism (Osborn, 1953).	Each team was given six random images from a catalogue of 100 random images drawn from past research on idea generation in design (Christensen, 2010). To avoid overlap with bio-cards, images relating to water or nature were not used in the pool from which the images were drawn.	Each team was given six Bio-cards created using the Ask Nature Biomimicry Taxonomy (Ask Nature). Six functions were picked at random from taxonomy functions relating to water, including functions relating to filtering, transporting, collecting and optimising water (consumption).

Table 7: Creative methods used by teams to generate ideas.

The five teams underwent the idea generation in parallel. For all teams, brainstorming was the first method, followed by the random images and bio-cards methods came in random order to avoid any ordering effects caused by ideas generated using previous methods that included providing participants with inspirational material. The facilitators initiated each new method with a short introduction, after which the participants started generating ideas.

Video and audio recordings were used to collect data from the idea generation process, resulting in a total of 5 hours and 36 minutes of video of design interaction from the five teams (varying from 62 to 73 minutes per team).

4.4.3   Data analysis

This section describes the data analysis method, focusing on the development of a coding scheme to capture multiple aspects of design activity.

4.4.3.1   Coding scheme development

As previously described in Section 4.2.3, Chi (1997) proposes a guide analysing verbal data. This guide is used to develop the coding scheme. Table 8 shows an overview of the coding scheme developed in response to the first aim of the study, which was to empirically investigate verbal reasoning at a micro-level of design activity.

Steps (adapted from Chi, 1997)	Coding ideas	Coding reasoning, version 1	Coding reasoning, version 2
1. Reducing or sampling the protocols	No reduction	Reduced to focus on idea-coded segments	Reduced to focus on idea-coded segments
2. Segmenting the reduced or sampled protocols	Version 1: Sentence Version 2: Word phrase	One to several sentences	Word phrase
3. Developing or choosing a coding scheme or formalism	Use of definitions from empirical studies of design activity	Use of propositional logic notation	Use of theoretical definitions of reasoning type characteristics Use of mutually exclusive codes
4. Operationalising evidence in the coded protocols that constitutes a mapping to some chosen formalism	Examples of coded protocols Inter-rater reliability check	Examples of coded protocols Inter-rater reliability check	Examples of coded protocols Inter-rater reliability check
5. Seeking pattern(s) in the mapped formalism	Qualitative observations and	Simple statistical tests (averages, counts, etc.)	Statistical tests Qualitative observations and

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	explanations of data		explanations of data
6. Interpreting the pattern(s)		Qualitative observations and explanations of data	Qualitative observations and explanations of data
7. Repeating the entire process, with option of coding at a different grain size		Repeat process to change segment size and coding formalism	

Table 8: Stepwise overview of the development of a coding scheme for micro-level reasoning in design.

4.4.3.2 Coding scheme for ideas

The first step of analysing the protocols involved the identification of ideas by the teams. Table 9 contains the code names and definitions.

Code name	Definition
Idea	Idea-coded segments are the uninterrupted sequence of utterances put forward by a participant proposing an idea.
Idea aspect	Idea-aspect coded segments are the utterances following *idea* codes but relating to the previous idea. Aspects of an idea can be multiple and stated by all participants. Aspects can also appear after breaks in the sequence of idea-related utterances.

Table 9: Code names and definitions for ideas used in the first step of the coding scheme.

As ideas involve solutions and sub-solutions (idea aspects; Badke-Schaub *et al.,* 2007), it is necessary to perceive ideas as being put forward in a distributed manner and at different levels of abstraction (Voss, 2006). More than one participant can contribute to the generation of ideas. Consequently, the protocols do not distinguish complete uninterrupted utterance sequences but rather groups of utterances relating to a proposed idea and related aspects of that idea. This group of segments is referred to as an *idea episode* (Chi, 1997). Table 10 shows examples from the protocols of an idea and the following aspect (same examples used in 2.1.4). The initial series of utterances from speaker A (segment 1) introduces and explores an idea and later the discussion spreads to the other participants contributing

to a further development (and partial recontextualisation of the idea) (segments 2-6). The example contains two *design moves*, one *idea* and one *idea aspect* and together form an *idea episode*.

Segment	Speaker	Utterance	Design move
1	A	Then I'm thinking, eh, it could also be to offer bathing for the guests, it could be… Like, winter bathing for instance, so every night at eight you drive out… And then there is something. Then you can bathe in the ocean.	idea
2	B	Instead of showering when they get home?	idea aspect
3	A	But then make this spa-area that is water saving. Then you don't need to shower in the morning either.	
4	B	Haha, no.	
5	A	If [you use] ocean water for bathing…	
6	C	I actually think that's pretty cool.	

Table 10: Example of idea and idea aspect design moves from the protocols.

4.4.3.3 Coding scheme for reasoning, Version 1: Propositional logic
The second step is to develop a coding scheme for reasoning.

In response to the traditional perception of reasoning in design in concordance with the Peircean formal logic (Dorst, 2011a; Koskela *et al.*, 2018; Roozenburg, 1993), an attempt at analysing reasoning according to the structure provided by propositional logic and its notation was conducted for two primary reasons. For one, propositional logic has been used widely in the research field to describe design reasoning (see e.g., Dong *et al.*, 2015; Galle, 1996b; Lloyd & Scott, 1994)). Additionally, the model of reasoning draws directly from the original Peircean formulation of the reasoning types (Peirce, 1980; Roozenburg, 1993). Roozenburg's (1993) model for the pattern of reasoning in design is based on a logical derivation of how to classify reasoning types based on which 'elements' of a design are used as *premise* and which are used as the *conclusion*, or 'target' of an idea.

A coding scheme was developed to test this proposed logical structure to determine the extent to which it is possible to reliably code for the proposed

elements in natural language and the validity of the proposed idea structure in the context of verbalised group conversation. The logic notation proposed by Roozenburg structures ideas as containing three elements (ibid.):

- *case*, for any statement describing a design,
- *rule,* for any generalisation upon which the inference 'rests', such as a rule of thumb, a validated law, or a scientific theory,
- *result,* for any derived property.

The data were segmented according to idea episodes. The coding of case, rule and result was done using Atlas TI software by highlighting the words signifying the presence of a code. The idea and idea aspect episodes were then coded according to the conclusion of the episode. The below list summarises the process:

1. Each episode was coded for the three proposed elements: case, rule or result.
2. The conclusion of each episode was determined by asking: "What is the episode trying to make me believe?"

Determining the type of reasoning (see Figure 2) was based on the different basic structures of each type depending on which of the above three elements were used as a premise or conclusion.

The process of coding using this formalism, however, proved challenging and infeasible for several reasons:

- *Case* and *result* codes were difficult to separate in the verbal protocols. This was primarily a consequence of how ideas are proposed in series, where the result of one argument immediately proceeds to become the case of the next, also described as nesting arguments (Voss, 2006).
- The *rule* code was largely left implicit between the people engaging in dialogue, and therefore not possible to consistently code and identify. The rule became part of the contextualised and informal use of language and was not made explicit during dialogue (Erduran, Simon, & Osborne, 2004).
- The segmenting of the utterances made it difficult to delineate each part of the reasoning activity in the protocol. This could be amended

by introducing a new segmenting process based on clauses rather than entire sentences.

- The formal and logical approach to understanding design reasoning in verbal data was time-consuming primarily because of the uncertainty in coding.

Given the above reasons, it was decided not to proceed with the first version of the coding scheme. However, the insights from the coding process showed that there was a need for a different coding scheme for identifying verbal reasoning that could provide:

- A finer segmentation of protocols to allow for capturing the series of smaller propositions made in verbal reasoning. This was necessary to identify the multiple occurrences of reasoning found in the nested inferences using the larger segmentation. This also provides empirical evidence for the statement by Rittel (1987) that a micro-level analysis of reasoning is necessary to understand design activity.
- A definition of reasoning types operationalised for coding that are mutually exclusive to avoid the somewhat arbitrary assessment of *case*, *rule* and *result* aspects of verbal utterances.
- The appropriation of the coding scheme to perceive verbal reasoning to be something different than propositional elements that together form logical inferences, such as an informal discourse between participants.

The development of the second version of the coding scheme is described in the next section.

4.4.3.4 *Coding scheme for reasoning, Version 2: Word/phrase level*
Table 11 illustrates the coding process. B1-B3 (Table 11) were coded separately, thus blinding the coders to previous coding results to avoid coder bias. The term *design move* is defined below.

Coding step	Coding A	Coding B1	Coding B2	Coding B3
Unit of analysis	Utterance level	Word/phrase level	Move level	
Hierarchical position and codes	*Idea episode,* consisting of one or more utterances, forming sequences of *idea* and *idea aspect* codes.	Word/phrase 1 [reasoning type: abductive, deductive, inductive or none] Word/phrase 2	Move 1 [breadth or depth]	Move 1 [theme X]
		Word/phrase 1 Word/phrase 2	Move 2	Move 2
		Word/phrase X Word/phrase Y	Move n	Move n

Table 11: Coding process and codes used for Study 1 - WORKZ.

Coding B1: Reasoning

To prepare for the coding of reasoning at a micro-level, segmentation was completed according to word/ phrases to allow the individual coding of utterances of the shortest possible meaningful length (Goldschmidt, 1991). To illustrate word phrases, Table 12 presents examples of word phrases (repeated from the example given in the section 2.1.4). As it can be seen, the phrases are very short and do not convey complete meaning in themselves, but depend on the proximity and context to other utterances.

Row	Speaker	Utterance
1	A	Then I'm thinking, eh,
2	A	it could also be to offer bathing for the guests,
3	A	it could be…
4	A	Like, winter bathing for instance,
5	A	so every night at eight
6	A	You drive out…
7	A	And then there is something…
8	A	Then you can bathe in the ocean.

Table 12: Examples of word phrases used as segmentation in the analysis of the protocols.

This process did not change the previous coding of *idea* and *idea aspect*. The reasoning coding was completed for segments previously coded as *idea* or *idea aspect*.

Table 13 presents the definitions of reasoning types used as a formalism to code for reasoning, derived from the literature review on the three reasoning types (abductive, deductive and inductive). The definitions were chosen to reflect the central characteristics of the three reasoning types describing different ways of reaching a conclusion from premises.

Reasoning code	Coding definitions
Abductive	• A hypothesis to account for what is desired or intended (Roozenburg, 1993) • Creating ideas (to solve a problem) from imagination (Johnson-Laird, 2009) • A belief held without proof or certain knowledge (Schurz, 2007) • Preliminary guess to introduce hypotheses (Fann, 1970)

Deductive	• Definitive and certain conclusion (Schurz, 2007)
	• Explicating hypothesis by suggesting consequences (Fann, 1970)
	• Prediction of result in a given frame (Fann, 1970)
	• Proves something must be (March, 1976)
	• Explores consequences of an abduction (Fann, 1970)
Inductive	• Tests a hypothesis with available data (Schurz, 2007)
	• Generalises from specific instance or idea (Reichertz, 2010)
	• Evaluates if something is operative (Fann, 1970)
	• Inferring from observed to unobserved (Schurz, 2007)
	• Inferring about future courses of events (Johnson-Laird, 2009)

Table 13: Code names and definitions for reasoning types used in the second step of coding scheme.

The segment length used here to code for reasoning deviates from other reviewed empirical studies of reasoning (e.g., Dong *et al.*, 2016; Galle, 1996a; Lloyd & Scott, 1994), as well as reviewed conceptual models (e.g., Dorst, 2011; Roozenburg, 1993) in that the applied segmentation (word/phrases) do not in themselves contain explicit premises, rules and conclusions. Rather, the coding of reasoning for such short segments occurs at a micro-level (Rittel, 1987) in which each reasoning segment is dependent on the reasoning pattern into which it enters. Analysed further, the verbal reasoning reflects mental models held by those addressed *(Badke-Schaub et al.*, 2007; Johnson-Laird, 1983), and the reasoning is verbally enacted and influenced by values and beliefs. In turn, it acts to propose a certain perspective (Dong, 2007; Stumpf & McDonnell, 2002).

The coding of reasoning types was restricted to the idea episodes coded in the first step of the coding process because the focus is on the inferences made during the generation of ideas.

To support the coding of reasoning types, a data-driven approach was taken by reviewing the transcripts and partially coding for reasoning using the above definitions to identify any common features of segments. This process resulted in the identification of three groups of indicator words that signify the three different types of reasoning. A similar approach was adopted by Christensen and Schunn (2009), amongst others, in the analysis of verbal concurrent protocols. The words were derived in Danish, as the data was in Danish and all analysis was completed in the original language. The full list

of indicator words is translated into English for the purpose of reporting in Table 14.

Reasoning	Abduction	Deduction	Induction
Indicator words	could, maybe, think, could be, imagine, probably, likely	so, then, therefore, that is, must be, as, can	I, me, you, they, we, them

Table 14: Reasoning type indicator words.

For example, the use of the word *probably* would indicate a belief or guess and thus relate to the definitions of abductive reasoning (refer to Table 13), while the word *so* would indicate something definitive or proven based on some previous premise and thus indicate deductive reasoning. In general, this initial analysis revealed the following common characteristics for the indicator words:

- Abductive reasoning: Conveys uncertainty and possibility and serves to frame the elaboration of an idea on the remaining segments of an idea episode.
- Deductive reasoning: Conveys a conviction, justified belief or consequence in response to a situation.
- Inductive reasoning: Often comes after the idea episode is completed and tends to co-occur with the use of pronouns (e.g., *I, you, we*) as a way for a person to judge or qualify an idea.

After the indicator words were established, the protocols could be coded.

Coding B2: Breadth and depth

Following the initial coding idea episodes into *idea* and *idea aspect*, each of the *idea generation design moves* were coded for being either a *breadth* or a *depth* move. Here, the term *move* refers to the series of segments describing either the first reasoning corresponding to an idea (coded *idea*) or following the series of segments of varying aspects of an idea (coded *idea aspect*).

The coding definitions came from studies describing the characteristics of *breadth* and *depth* moves, as reviewed earlier. *Table 15* presents the coding guide definitions. The coding scheme was applied to all *idea-aspect* moves,

since *idea* moves by definition concerned the proposition of a new idea, that is, not explicitly continuing from a previous idea, and were thus defined as a new frame for addressing the design task (Atman *et al.*, 2005; Ball *et al.*, 1997).

Code	Coding definitions
Breadth	• Problem understanding (Ball *et al.*, 1997) • Task clarification (Ahmed-Kristensen & Babar, 2012) • Parallel variant solution to realised problem (Günther & Ehrlenspiel, 1999) • Not following a strict top-down hierarchical movement (Günther & Ehrlenspiel, 1999) • Principle of earlier solution used for variation (Günther & Ehrlenspiel, 1999) • Identify need, purpose or reason for design (Atman *et al.*, 2005) • Focus on problem definition (Atman & Bursic, 1998) • Solutions that re-focus the problem (Wiltschnig, Ball & Christensen, 2013)
Depth	• Solution generation (Ahmed-Kristensen & Babar, 2012) • Solution development and evaluation (Atman *et al.*, 2005; Ball *et al.*, 1997) • Working on serial variants of solution to problem (Günther & Ehrlenspiel, 1999) • Modelling, building, measuring (Atman *et al.*, 2005) • Elaboration of solution (Wiltschnig, Ball & Christensen, 2013)

Table 15: Code definitions for breadth and depth moves in design activity.

Coding B3: Idea themes

One approach to determining the links between ideas in design idea generation is the use of linkography (Gabriela Goldschmidt, 2014). While the present study acknowledges the advantages of using linkography to determine links between moves in design activity, there are some caveats. Traditionally, to validate and test reliability of analyses using linkography, agreement between expert judges is commonly used, potentially introducing bias. In an attempt to apply a more objective means of coding, van der Lugt

(2001) proposes using measures of agreement using Kappa-calculation, comparing relative agreement between judges and correcting for random chance agreement (Cohen, 1960). However, such coding is very time consuming since each move requires backwards evaluation against an accumulating number of moves.

An alternative method to interpret content, and thus infer links between moves in design activity, is to use content analysis (Krippendorff, 2004). Specifically, applying a directed content analysis of the themes, or subject matters, of moves is appropriate for the type of data analysed in the present study (Hsieh & Shannon, 2005). Since the differences in language use of the participants in the groups varies their verbal representations, the usefulness of manifest keywords is limited. A qualitative analysis of the moves revealed that certain themes re-occurred at several points in the idea generation of the groups. Since these themes were different in their manifest representation, a latent analysis of the themes was desirable to capture when a move linked to other moves. Consequently, an approach was taken that involved the main author assigning a single theme to each move to describe the subject matter of the move, after which a second coder did the same to determine reliability.

Table 16 shows the full example of the parts shown in the previous sections. The example is also reported in section 2.1.4. Apart from the coding of idea, idea aspect, and design moves, the table shows examples of *reasoning* types (column B1), *breadth* and *depth* classification (column B2), *idea theme* (column B3).

Protocol data			Coding steps			
Row	Speaker	Utterance	A	B1	B2	B3
1	A	Then I'm thinking, eh,	idea			
2	A	it could also be to offer bathing for the guests,	idea	abductive		
3	A	it could be…	idea			
4	A	Like, winter bathing for instance,	idea	abductive	Breadth	Showering

5	A	so every night at eight	idea	deductive		
6	A	You drive out…	idea	deductive		
7	A	And then there is something…	idea			
8	A	Then you can bathe in the ocean.	idea	deductive		
9	B	Instead of showering when they get home?	idea aspect			
10	A	But then make this spa-area	idea aspect	deductive		
11	A	that is water saving.	idea aspect	deductive		
12	A	Then you don't need to shower in the morning either.	idea aspect	deductive		
13	B	Haha, no.	idea aspect			
14	A	If [you use] ocean water for bathing…	idea aspect			
15	C	I actually think that's pretty cool.	idea aspect	inductive	Depth	Showering

Table 16: Example of the protocols used in the research, including dialogue and data coding

4.4.3.5   Reliability of coding schemes

The protocols were coded by the author as well as a trained second coder. To determine the replicability and operationalisation of the coding scheme, Cohen's kappa was calculated for inter-coder reliability (Cohen, 1968). Cohen's kappa calculates the actual percental agreement between coders and deducts the percental chance of randomly agreeing. This effect is particularly large when only using a few codes, as is the case here, because there will always be a larger chance of randomly agreeing between two different code types than when many codes are used. Hence, while the kappa values are not the highest, the actual levels of agreement between the coders was in all cases above 80%. Table 17 reports the kappa values for each coding step.

Coding step	Kappa value	Segments coded
Coding step A: Idea and aspect	0.710	460
Coding step B1: Reasoning types	0.610	353
Coding step B2: Breadth and depth moves	0.693	65
Coding step B3: Theme of moves	0.738	111

Table 17: Summary of inter-coder reliability checks.

Common for all reliability calculations is that they are considered high (Fleiss, 1981) or substantial (Landis & Koch, 1977) and justify the reliability of the respective analyses. All coding steps were completed between the author and a colleague as second coder. No notable patterns of disagreement were apparent in coding Steps A, B2 and B3. In Step B1 (kappa = 0.61), the primary source of disagreement came from the *deduction* code in which the second coder tended to code fewer occurrences of the code than did the first coder. Since the disagreements occurred in common appearances of multiple deduction codes in a series of uninterrupted segments, the source of error was adapted to the code definition for coding the remaining protocols. For all coding steps, disagreements between coders were discussed, and a common decision was made as to which code to apply.

The resulting coding scheme for reasoning responds to the first aim of the study, showing that a reliable method for coding micro-level reasoning in idea generation is possible. The results chapter will go into further detail on the coding scheme results in relation to identifying reasoning in design activity.

4.5 STUDY 2 – SMART

The second study was conducted as part of an innovation programme – SMART - in which participants from small- or medium-sized enterprises (SMEs) were trained in using a product innovation process to ensure creation of products that generate greater value at lesser costs. The author participated in the SMART project as the facilitator in the activities involving idea generation and concept development. Hence, the study provided a basis for collecting real-world data from ongoing industry product development projects. It was in this context that the idea generation activity data used in the study was collected.

The study addresses the research issue:

1. Using reasoning patterns taking place when generating an idea to predict how that idea is later evaluated to be valuable.

The study draws on previous studies of reasoning in design activity to identify specific reasoning characteristics that are expected to lead to certain evaluations of idea value for the respective company. Two sets of hypotheses address this research issue. The role of any framing effects was investigated (**HS2a**) along with the ability to predict idea evaluation through reasoning patterns (Hypotheses **HS2b-e**).

4.5.1 Idea evaluation categories

Because the below derivation of the hypotheses makes explicit use of the idea evaluation categories, they are briefly explained here. Ideas were sorted into four categories:

Accept: Ideas that were accepted for further use in the ongoing development projects. These ideas were often of an incremental character.

Analyse: Ideas that were deemed valuable to the project, but required more clarification to determine whether to proceed.

Put on hold: Ideas that were determined to have potential value but were beyond the scope of the ongoing development project. These ideas were often radically different from existing solutions.

Reject: Ideas deemed not valuable to the projects.

A full description of the procedure is provided in Section 4.5.2.

4.5.1.1   Framing effects of reasoning types on idea evaluation

First, the role of abductive reasoning influences idea evaluation and was found to indicate the generation of new frames or perspectives for addressing a design task and thus also the uncertainty that triggers the occurrence of deductive reasoning to simulate and explore possible solutions. Initial analyses showed a significant difference between the *put on hold* and *accept* categories when judging from the first occurrence of reasoning for the idea. The former was more often started by abductive reasoning, and the latter began with deductive reasoning (IPDM paper). The study found no other significant differences between *reject* and *analyse* or any other categories. Since the study used only a partial data set (only 2 companies) and the statistical test was not sufficient, the hypothesised relationship does not specify idea evaluation categories, instead only predicting a correlation that is investigated further afterwards.

HS2a states that:

Idea evaluation is dependent on the use of deductive or abductive reasoning to initiate idea episodes.

4.5.1.2   Reasoning patterns to predict idea evaluation

Results from previous research show that risk averseness (Blair & Mumford, 2007) and a focus on operative goals (Licuanan *et al.*, 2007) will result in biases against ideas containing higher degrees of novelty. Since the *analyse* idea evaluation category includes ideas assessed as having a high degree of risk, complexity and/or development effort (elaborated upon in the method section), there is reason to expect those ideas to also involve higher proportions of abductive reasoning. **HS2b** states that:

The proportion of abductive reasoning is higher for ideas evaluated as 'put on hold' and 'analyse' compared to ideas categorised as 'accept'.

The amount of reasoning present when generating an idea is expected to be indicative of a level of interest in the idea simply because more effort is put into generating the idea. This assumption is supported by the finding that an increased amount of reasoning leads to a higher accumulation of interrelations to later idea generation activity, which is indicative of creative
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quality (Gruber, 1980). On the premise that a group of experts in a field can distinguish good ideas from less useful ideas (Amabile, 1996; Onarheim & Christensen, 2012), it was expected that accepted ideas would contain numerically more reasoning than other ideas. **HS2c** states that:

Ideas evaluated as 'accept' contain higher degrees of reasoning than other evaluation categories.

Aside from the hypotheses, it is of interest to analyse the remaining categories to identify any patterns in order to better characterise the behaviour leading to such evaluations. Therefore, a second aim of the study was to investigate whether reasoning patterns can explain characteristics of creative activity that cause certain types of idea assessment according to their value to an ongoing design process.

Hence, the analysis stipulates that the occurrence of reasoning patterns such as the proportion of abductive reasoning in ideas and the effort of reasoning can in part provide an explanation for findings in the literature related to biases and characteristics underpinning the assessment of ideas. The aim is not pursued through the formulation of hypotheses but instead draws on the results of the above hypotheses and through the qualitative analysis of the protocols, illustrated by the use of an example from the protocols.

4.5.2 Study description

Data was collected from four different Danish companies. All companies were small- or medium-sized enterprises (SMEs), and were part of a project that involved the development of a new generation of an existing product (the earlier-described SMART project). Data used for the present study came from individually conducted half-day sessions during which the companies generated ideas for a new product based on analyses of users and customer wishes and needs for an improved product as well as analyses of competitors' products already existing in the market.

Table 18 summarises the details of the companies and their participants.

Company and product type	Number of employees	Participants' roles in company	Team size
A. Construction tools	~10	Project Manager, Design Engineer (2), Industrial Designer	4
B. Food refrigeration	~200	Technical Support Manager, Design Engineer (2), Production Manager, Assembly (2), Production Planning, R&D Manager, Product Owner	9
C. Waste management equipment	~80	Head of Development, Design Engineer, Production Manager, Purchasing Manager, Engineering Consultant (2), Sales Manager, Project Manager, Export Manager	9
D. Agricultural machinery	~350	Project Coordinator, Design Engineer (2), Purchasing (2), Technical Assistant, Workshop Manager, Marketing Manager, Assembly, Technical Development Manager	10

Table 18: Details of companies used for data collection.

A total of 32 people (28 male, 4 female) participated in the study across the four companies. Table 19 summarises the participants' demographics.

Participants' demographics					Previous work experience		
Partici pant	Gend er	Com pany	Job function	Years of experience	Problem solving	Technical design	Creative methods
1	M	A	Industrial Designer	4	X	X	X
2	M	A	Project Manager	6	X	X	X
3	M	A	Design Engineer	6	X	X	X
4	M	A	Design Engineer	2	X	X	X
5	M	B	R&D Manager	27	X	X	X
6	M	B	Product Owner	25	X	X	X
7	M	B	Assembly	8	X		
8	M	B	Production Manager	40	X	X	X
9	F	B	Design Engineer	2	X		X
10	F	B	Assembly	30	X		
11	M	B	Design Engineer	27	X	X	X
12	M	B	Production Planning	14	X	X	
13	M	B	Technical Support Manager	15	X	X	
14	M	C	Export Manager	21	X		
15	M	C	Sales Manager	15	X		
16	M	C	Design Engineer	30	X	X	X

17	M	C	Project Manager	24		X	
18	M	C	Purchasing Manager	24	X	X	X
19	M	C	Production Manager	23	X	X	X
20	M	C	Engineering Consultant	26	X	X	X
21	M	C	Head of Development	30	X	X	
22	M	C	Engineering Consultant	34	X		X
23	M	D	Purchasing	8	X		X
24	M	D	Technical Development Manager	5	X	X	X
25	F	D	Project Coordinator	20	X	X	X
26	M	D	Marketing Manager	14	X		X
27	M	D	Design Engineer	3	X	X	X
28	F	D	Purchasing	8			
29	M	D	Workshop Manager	20	X	X	
30	M	D	Technical Assistant	15		X	
31	M	D	Design Engineer	12	X	X	X
32	M	D	Assembly	28	X		
				Average = 17.7 [SD = 10.5]	91%	69%	63%

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4.5.3   Procedure

As described, the study took place as part of an ongoing product development project for four SMEs focusing on developing new versions of existing products. The SMEs followed the same product development process in which they had previously undertaken analyses of a) user and customer needs and desires and b) a mapping of existing solutions through reverse engineering of competitor products and cost calculations. After the above had been completed, the companies formulated 3-5 general criteria for the solutions developed.

Following this, idea generation sessions began. The idea generation session was facilitated by the author. To avoid biases from the author, the following steps were taken:

The idea generation activity and evaluation activity used in the study was designed to use established principles and tasks for idea generation and evaluation. For idea generation, the basic principles of brainstorming were followed, i.e. a combination of individual brainstorming and verbal presentation of ideas between participants with emphasis of not being critical, building on each other's ideas and to make sure actual ideas are presented and not only concepts. For idea evaluation, the researcher facilitator was not involved, as the process was facilitated by an external consultant also blind to the research hypotheses and aims.

Great care was taken not to intervene with the already on-going development project and the study was designed to accommodate to the process and avoid intervention in this regard. This is described below.

Finally, the participants were not revealed any information about the nature or aims of the study. They were merely told they were recorded for on-going research so they could consent.

Participants were instructed to engage in a combination of individual brainstorming for a few minutes at a time, followed by a plenary explanation of generated ideas with the other participants. During the individual brainstorm, participants were provided with sticky notes on which ideas could be sketched and described using a few words. During the collective

portion, participants were asked to withhold judgement and criticism and instead focus on creating ideas based on those presented by other participants or to suggest improvements. This process was repeated in every round. No round of idea generation ever exceeded 30 minutes. The author guided this process and provided keywords from the previous analyses in each round to maintain a flow of ideas being generated and variety in the type of ideas generated, such as different sets of criteria for focus areas for generating ideas.

To reflect the previous analyses of needs and existing solutions, the idea generation session was structured to consist of between 3 and 5 rounds of idea generation with shifting foci. For all companies, one round focused on having no rules (open brainstorm), at least one round focused on user or customer insights and at least one round focused on cost reduction based on the analysis of existing solutions.

As part of the product development process, the companies were asked to provide participants reflecting the various disciplines engaged across the stages of the product development process.

The sessions were recorded using video and audio.

Following the idea generation rounds, the sticky notes containing ideas were collected, and a smaller group in each company (in all cases including the project manager and at least one engineer) underwent an idea evaluation process to sort the generated ideas according to their value and utility to the further development process, described in the next section (Cooper, 1990; Cooper & Edgett, 2010). The evaluation system assessed each idea on four dimensions:

- Fit to ongoing development project (product requirements)
- Value to customer/user
- Company strategic fit
- Risk, complexity and effort of idea realisation

The four dimensions were each evaluated according to local criteria describing appropriate products or solutions by the companies. The dimensions were derived from the Stage Gate model proposed by Cooper

(Cooper, 1990) and adapted to ensure a fit to the process (Cooper & Edgett, 2010).

All ideas were evaluated in a 2 × 2 matrix. The criteria were a good or poor fit to the primary product requirements (on the vertical axis) and whether the idea would provide a high or low value for the customer/user (on the horizontal axis). Ideas evaluated high on both axes (i.e., the top right quadrant) were moved to the second matrix for further evaluation. Ideas evaluated high on customer/user value, but low on fit to product requirement, were assigned to the *put on hold* category, indicating that the idea would be potentially valuable in other development projects in the company. Ideas falling in the two remaining quadrants were categorized as *reject*, indicating no further value to the company.

Ideas from the top right quadrant of the first matrix were moved to the second matrix for further evaluation. The second 2 × 2 matrix evaluated whether ideas had a high or low value to the company strategy (on the vertical axis) and whether the idea had a low or high risk, complexity and/or development effort (on the horizontal axis; low being a positive value). Ideas determined to be high in value to company strategy and low on risk, complexity and/or development effort (i.e., the top right quadrant) were assigned to the *accept* category and thus deemed directly useful for the further design process. The ideas considered to be of high value to the company strategy but also high on risk, complexity and/or development effort, and vice versa (i.e., top left and bottom right quadrants), were assigned to the *analyse* category, signifying an idea needing some further analysis and clarification before a final decision could be made. Ideas falling in the remaining quadrant were categorized as *reject*, indicating no further value to the company. Figure 4 illustrates the idea evaluation matrices.

MATRIX 1 / MATRIX 2
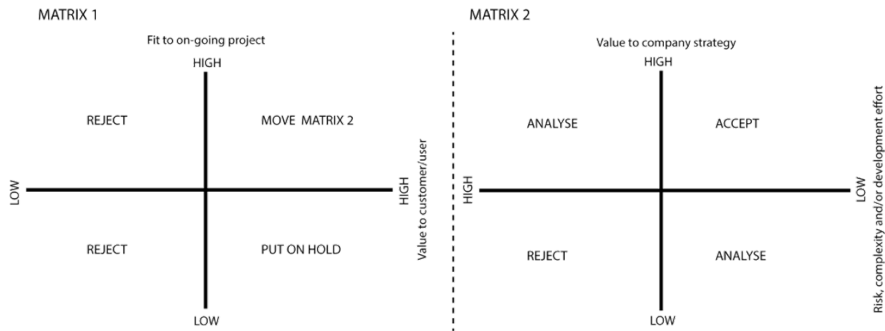
Figure 4: Dimensions used for evaluating ideas.

All criteria were checked against 3-5 requirements that the end-product must adhere to based on the company's objectives for the solution in development. The requirements were derived from the previous assessment of customer/user needs and competitor product analyses and reflected the overall aim (the same for all participating companies) to create a new generation of an existing product (i.e., incremental innovation).

The placement of the ideas on the evaluation matrices was photographed for later analysis.

The evaluation method was introduced by an external consultant and involved a consensual assessment of each idea by a group of company employees according to the ongoing development project. According to the consultant, the evaluation method served to:

-   Act as a boundary object to facilitate a discussion between those evaluating the idea. Hence, using the theoretical notion of boundary object (Star, 2010), the method creates alignment and clarification as to how the idea can – or cannot – add value to the process.
-   By creating a discussion on each idea according to the criteria described above, the intention of the method is also to create an objective discussion on each idea and thus attempt to break up internal power structures between those evaluating ideas (Bucciarelli, 2002).

The assessment method differs from assessment criteria and selection processes described in the literature (refer to Section 3.3), and, as argued earlier, the aim was to apply an idea assessment approach that is more

applicable and valid to design practice. Hence, by evaluating each idea on as many as four general criteria and a short list of requirements, the criteria functioned to filter out ideas with no value to the ongoing project and thus encouraged ideas with immediate potential for meeting the practical needs at hand (Keshwani *et al.*, 2013). Further, the dimensions for evaluating the ideas are similar to the overall considerations when following stage-gate processes (Cooper & Edgett, 2010).

4.5.4 Data analysis

The protocols were transcribed and coded for the presence of idea and idea aspect as well as for reasoning, corresponding to coding steps A and B1 described in Section 4.4.1.

After the sessions, the sticky notes representing ideas and their final evaluation category were mapped to the protocol to ensure a link between the protocols and the outcome idea value. This was used in the statistical analyses presented in Chapter 0.

Having presented and described the method of both studies, the next section discusses the methodological limitations.

4.6 METHODOLOGICAL LIMITATIONS

As introduced in the beginning of the chapter, some limitations exist in the chosen research approach. These are described below in relation to the chosen methodology.

4.6.1 Number of participants

Access to experienced participants is a barrier to research, as also discussed earlier in Section 4.2.3. Hence, the relatively low number of participants (15 + 31 for studies 1 and 2, respectively) was compensated for by a very fine-grained analysis of design activity that in itself will encompass many segments in the given unit of analysis – the micro-level. Hence, the issue becomes a trade-off between keeping a manageable number of segments to code while using high-quality data. An alternative way to recruit greater numbers of participants would be to use students; however, reasoning and behaviour in novices (i.e., students) has been shown to differ from that of experienced designers (Ahmed & Christensen, 2007). Therefore, it was decided to focus entirely on experienced participants to ensure a higher degree of representation of practice.

4.6.2 The use of different methods for generating ideas

As described for both studies, the participants were asked to generate ideas using different methods for Study 1 and using different criteria for study 2. While these methods arguably influenced the reasoning and creative behaviour of the observed idea generation activity, these will be considered when performing statistical analyses of the study data to control for any effects on reasoning patterns and idea value.

4.6.3 The role of facilitators

In Study 1, the student facilitators did in some cases join in the generation of ideas. However, this was mainly to encourage the group to continue to generate ideas. The involvement of the facilitators was accounted for in the analyses.

In Study 2, the author facilitated the sessions in the companies. To ensure that the facilitation was the same both across companies and across the constraints used for generating ideas, the sessions were facilitated in the same way for all companies. In order to reduce bias and effects on behaviour,

the participants were not informed of the aims of the research and told only that the author was recording the sessions for research purposes. Furthermore, the author did not know the results of - or otherwise influence - the later idea evaluation, thus reducing the risk of introducing bias towards some ideas over others.

4.6.4   Practice-based idea evaluation method

The use of a practice-based idea evaluation method has the drawback of not being scientifically validated. However, given the earlier discussion of the general lack of appropriate methods for evaluating ideas, the present work retains the validity of relying on a) following a stage-gate process (Cooper, 1990), b) using an experienced facilitator to guide the process and c) the ability of the employees of the company to use their domain-specific experience to be able to implement the method in a way that reduces bias (Keshwani *et al.*, 2013).

All the limitations addressed here from a methodological perspective will be revisited in the discussion of the implications of the results.

4.7 SUMMARY

This chapter presented the research approach of this project.

The four overall research questions posed were considered from a methodological perspective to emphasise the need for conducting an empirical investigation of reasoning in design and to correlate reasoning to creative behaviour and idea value.

Next, appropriate methods for responding to the needs were reviewed along with discussions on how to combine tenets of quantitative and qualitative methods to provide a strong framework for the research. The choice was to use verbal protocol analysis to collect uninterrupted verbal data from design idea generation and to apply a data-driven approach for developing an appropriate coding scheme.

The two studies conducted as part of the research were presented along with a coding scheme for analysing verbal reasoning in micro-level design activity, which was found sufficiently reliable to address the aims of the research.

Finally, the methodological limitations of the chosen methods were discussed according to the review of appropriate methods. Further, the methodological limitations will be considered when reviewing the overall limitations and avenues for further research later in the thesis.

5 RESULTS

This chapter is divided into three sections. The first presents a comparison of the overall descriptive and quantitative findings across the studies, and the second and third present the results of the hypotheses and other research aims for each study.

5.1 COMPARISON OF THE STUDIES

The section presents a summary of coding steps A and B1 (refer to Section 0) pertaining to identifying *idea* and *idea aspects* as well as the overall *reasoning types* of the data. The section also presents an analysis of the distribution and proportions of the reasoning types across the studies.

5.1.1 Coding results for ideas and reasoning

Table 20 summarises the overall descriptive numbers from the studies.

Variable		Study 1 – WORKZ	Study 2 – SMART
Ideas	Number of ideas	218	293
	Number of idea aspects	258	364
	Ratio of idea aspect to idea	1.18	1.24
Group and participants	Number of groups	5	4
	Total number of participants	15	31
Segments	Total number of segments	5792	6518
	Proportion of ideas	35% (2047)	59% (3866)
	Proportion of reasoning	83% (1698)	87% (3354)
Reasoning proportions - totals	Abductive	21% (349)	13% (435)
	Deductive	72% (1226)	74% (2472)
	Inductive	7% (123)	13% (447)

Table 20: Comparison table for coding results for ideas and reasoning across the two studies.

5.1.2   Segments

Design-move level segments: With regards to the segments coded for idea and idea aspect and later reasoning types, some differences were observed. For Study 1, 35% of all utterances were related to actual idea generation, while for Study 2 this number was 59%. This difference is primarily explained by the groups in Study 1 spending some of their time discussing the design task (which was new to them), whereas in Study 2 all participants were well acquainted with the task as it was an on-going development project.

Word-phrase level reasoning segments: The actual proportions of reasoning occurring during the idea generation activity (coded idea and idea aspect) were more similar, at 83% for Study 1 and 87% for Study 2, immediately suggesting a threshold of reasoning activity that far dominates the actual activity of generating ideas. The high proportion of reasoning was to be expected, since the first round of coding had already filtered out utterances unrelated to reasoning about ideas.

5.1.3   Ideas and idea aspects

For generated ideas, the results show comparable numbers of ideas generated across the studies, regardless of the number of participants in each group. This is expected since there was approximately the same amount of time available to speak when all ideas were shared and elaborated upon between the groups.

Furthermore, the results show that despite the differences in the type of design task undertaken in the studies, there are similarities in how the ideas develop, with a ratio of 1.18:1 *idea aspects* per *idea* for Study 1 and 1.24:1 for Study 2, indicating that ideas developed beyond the initial utterance of the idea, both because the *idea aspect* code signified one or more participants in the group contributed, and also because additional aspects indicated further effort and development of ideas.

As observed from the protocols of both studies, the reasoning not coded for idea and idea aspect was most often related to understanding the task, and other talk was either unrelated to the task or about the process itself.

5.1.4 Proportion of reasoning occurrences

The proportion of reasoning is part of the research topic and thus the hypotheses of the research. The hypotheses are tested in Section 5.2.1, while this section provides a quantitative overview of the reasoning proportions across the studies.

In relation to the total amounts of reasoning identified, Table 20 depicts the distribution and Figure 5 illustrates the numbers and distributions. As shown, there is an almost identically high proportion of deductive reasoning present in both study protocols – 72% for Study 1 and 74% for Study 2. There are differences for abductive and inductive reasoning types, possibly explained by the focus of the two studies, in which Study 1 (with a higher abductive proportion) was focused on new ideas as part of an innovation workshop, whereas Study 2 was concerned with internal company development projects focusing on incremental innovation (new version of existing products). Hence, it is likely that the proportion of abductive reasoning is correlated to the nature of the design task. This will be explored at length at several points later in the thesis.
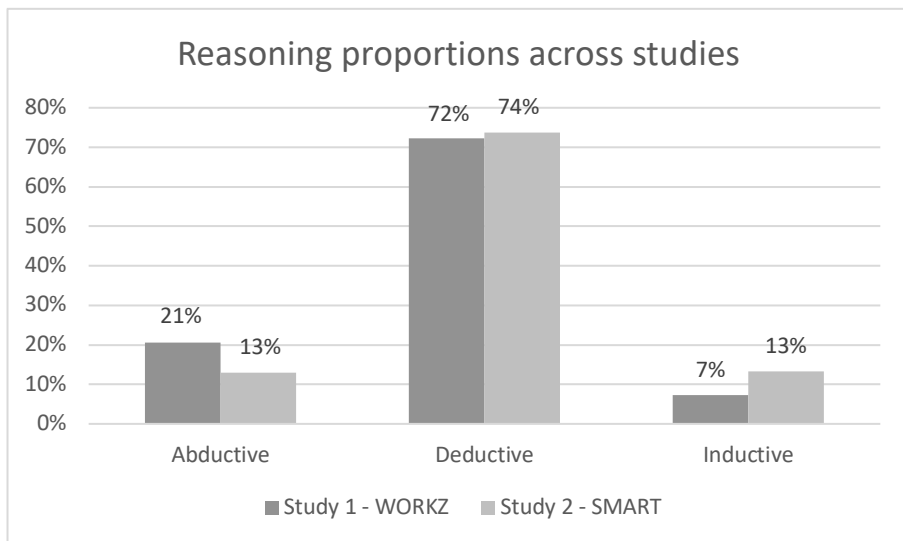
Figure 5: Reasoning proportions for the two studies.

Table 21 summarises the results of the coding for reasoning for the groups in each study. As the data shows, the variations in reasoning proportions in the groups are relatively small compared to the study totals. Further, the

data shows that of all 9 groups in the studies, 7 adhered to the general pattern of deductive reasoning being most prevalent, followed by abductive and finally inductive. Of the remaining two groups, both engaged most often in deductive reasoning, one group displayed an equal amount of abductive and inductive reasoning (Company 3 – Study 2), and the last group had a higher proportion of inductive reasoning (Company 4).

Variable	Data	Abductive	Deductive	Inductive
Reasoning count	Total	796	3.698	558
	Study 1 - WORKZ	349	1.226	123
	Study 2 - SMART	447	2.472	435
Reasoning proportions	Total	16%	73%	11%
	Study 1 - WORKZ	21%	72%	7%
	Group 1	19%	68%	13%
	Group 2	23%	74%	7%
	Group 3	22%	69%	9%
	Group 4	19%	73%	8%
	Group 5	26%	70%	4%
	Study 2 - SMART	13%	74%	13%
	Company 1	17%	70%	13%
	Company 2	15%	76%	9%
	Company 3	10%	80%	10%
	Company 4	11%	74%	15%

Table 21: Summary of coding results for reasoning types across individual groups.

Further investigating the distribution of reasoning types in each idea episode, Figure 6 shows the average proportions of reasoning types divided into idea episode thirds (i.e., showing the proportion of reasoning types in the first, middle and last thirds in terms of utterances in each idea episode). The first part is the first third of an idea episode, counted by reasoning occurrences, and rounded down. The same procedure was applied for the last portion, but using the last third of reasoning occurrences in an idea

episode, rounded down. Remaining reasoning occurrences were assigned to the middle third.

The analysis is fully described in Section 5.2.1, but the figure presented here presents results compared across the studies, showing that a similar pattern exists for the overall proportions of reasoning types present in the protocols as for the idea parts. The largest relative differences are present in the proportion of abductive reasoning in the first parts of ideas (37% for Study 1 vs. 21% for Study 2), a difference that persists in abductive reasoning across all three parts of the ideas. The difference in abductive reasoning is compensated for by a combination of deductive and inductive reasoning that both appear in higher proportions in Study 2 compared to Study 1 across all parts of ideas. The results shown in Figure 6 suggest that a pattern of fundamental reasoning in design exists within idea generation, as elaborated in Section 5.2.1.
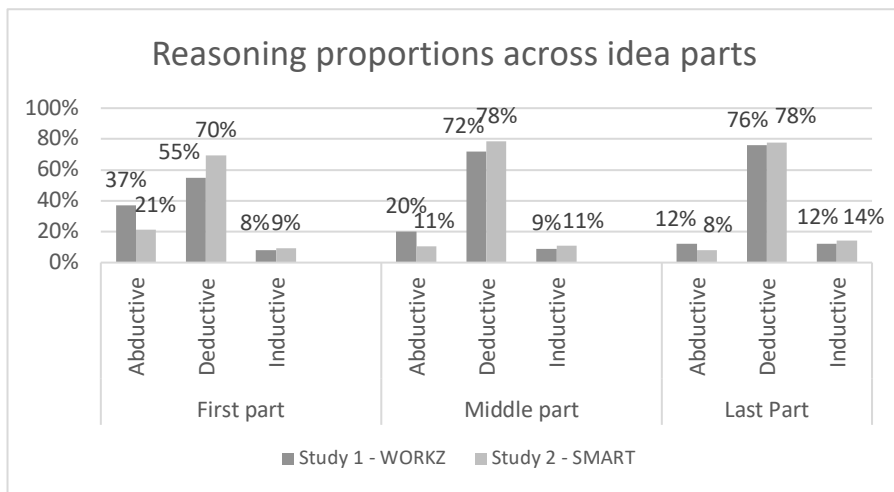
Figure 6: Reasoning type proportions across first, middle and last idea episode parts.

The next sections of the chapter present the results of the two studies individually. Both the results of the tested hypotheses as well as qualitative analyses address the overall issues and questions of the research.

5.2   STUDY 1 – WORKZ

Next, the results of Study 1 – WORKZ are presented. As mentioned earlier, the study aimed to address the research issues of:

Analysing micro-level reasoning in design through the development of a coding scheme for reliably identifying reasoning patterns from concurrent verbalisations.

Determining the patterns of reasoning taking place during idea generation by analysing both the quantitative reasoning patterns and the qualitative observations possible from groups engaged in idea generation.

Correlating reasoning patterns to creative behaviour in problem-solving activity in design via investigating the correlation between reasoning patterns and problem-solving behaviour.

The first part presents the tests of hypotheses **HS1a**, **HS1b** and **HS1c** pertaining to the distribution of reasoning types in ideas generated. Examples from the protocols illustrate the qualitative observations. The second part examines hypotheses **HS1d**, **HS1e**, **HS1f**, **HS1g** and **HS1h** pertaining to the relationship between reasoning patterns and problem-solving activity and behaviour. Again, examples from the protocols illustrate the qualitative observations.

5.2.1   Reasoning type distribution in idea episodes

This section addresses the overall research aim of analysing micro-level reasoning in design and determining the patterns of reasoning during idea generation. Hence, the focus here is on investigating the actual distribution of reasoning types (i.e., reasoning patterns) in generated ideas in order to identify these patterns from empirical data.

As presented earlier, a set of hypotheses predicted the following development of reasoning patterns in idea episodes:

HS1a:

Abductive reasoning (compared to deductive and inductive) is relatively concentrated in the first part of the verbal realisation of an idea.

HS1b:

Deductive reasoning (compared to abductive and inductive) is relatively concentrated in the middle part of the verbal realisation of an idea.

Further, an exploratory question as to the presence of inductive reasoning in the last parts of ideas is pursued.

Figure 7 illustrates the distribution of reasoning types across the three parts, showing the overall reasoning patterns in the data.
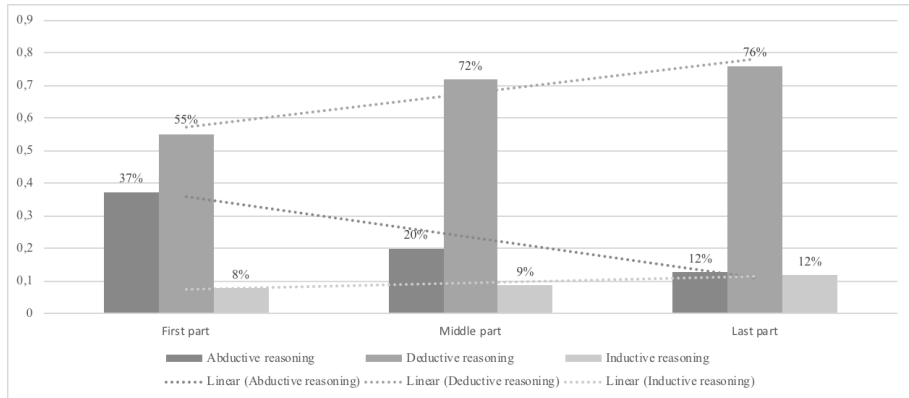
Figure 7: Proportional distribution of reasoning by idea parts with trend lines to emphasise direction.

To test hypotheses **HS1a** and **HS1b** and the question of inductive reasoning, a series of Wilcoxon signed-rank tests were completed. A non-parametric test was applied (as opposed to paired *t*-tests or other parametric tests) since the proportional distributions of reasoning in the three idea episode parts are not normally distributed but do show a symmetrical shape in differences between the groups (i.e., the difference of reasoning proportions between each reasoning type across first, middle and last parts of ideas). Table 22 presents the Wilcoxon signed-rank tests necessary to test hypotheses.

Reasoning type	Tested groups	Z	N	Significance
Abductive	First part, middle part	-5.698	203	p < .001
	First part, last part	-6.716	203	p < .001

Deductive	Middle part, first part	-4.984	203	p < .001
	Middle part, last part	1.090	203	p = .276
Inductive	Last part, first part	-1.841	203	p = .066
	Last part, middle part	-1.397	203	p = .162

Table 22: Results of Wilcoxon signed-rank tests of hypotheses HS1a, HS1b, and HS1c.

Table 22 summarises the test results. Note that of the 218 total ideas, 203 were of a length that allowed for analysis of reasoning proportions across all three parts. That is, short idea episodes did not contain a sufficient number of reasoning occurrences to allow distribution across all three idea episode parts.

Abductive reasoning accounted for 37% of total reasoning in the first part of ideas and significantly decreased to 20% in the middle part ($Z = -5.698$, $p < .001$) and 12% in the last part ($Z = -6.716$, $p < .001$), supporting **HS1a**.

In the middle part, deductive reasoning accounted for 72% of total reasoning, thus significantly decreasing to 5% in middle part ($Z = -4.984$, $p < .001$), while actually increasing from the middle (72%) to last part (76%) ($Z = 1.199$, $p = .276$). This result only supports **HS1b** from the middle to first parts, while a direction opposite to what was expected is observed from the middle to last parts. The hypothesis is thus partially supported.

As for the exploratory question as to the role of inductive reasoning, the results showed that inductive reasoning accounts for 12% of total reasoning in the last part of ideas, 9% in middle parts and 8% in the first part.

Since the facilitators took part in the idea generation to a limited degree (287 segments coded for reasoning, equivalent to 5% of all reasoning), the proportional distributions and statistical tests were re-calculated to identify any biases in reasoning patterns caused by the facilitators (despite them being blind to the study aims and hypotheses). The procedure excluded all complete idea episodes in which a facilitator uttered any reasoning (i.e., segments by facilitators coded for any of the reasoning types), resulting in a reduction of 79 idea episodes. Pertaining to proportional distributions using the reduced data, the results were very similar, showing differences up to 1.5 percentage points. A re-run Wilcoxon signed-rank test confirmed this by

producing the same significant and non-significant results as reported in Table 6. As the analysis shows, the participation of facilitators seems to not have interfered with the results.

Picture 1 shows a screen dump from the recordings of a group participating in Study 1.

Picture 1: Screen dump from the recorded material from a group participating in Study 1.

5.2.2   Reliability tests of coding scheme for reasoning types

To assess reliability of the above results, a string of analyses were conducted. The analyses aimed at R1) assessing if the results from the episode split into thirds could be replicated with a mean episode split; R2) assessing whether the results depended on temporal development within sessions (e.g., if abductive reasoning happens mainly early in a session) by splitting the transcripts into early/late parts and re-running the analyses; R3) testing reliability of the results in each individual group; and finally R4) carrying out the same conceptual analyses at a different grainsize by investigating the temporal ordering of individual arguments *within* each episode (as opposed to *between* as in the main analysis).

R1)   All the main results could be replicated with a mean episode split: Wilcoxon signed-rank tests found that abductive reasoning was more

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prevalent in the first half (Z = -5.756, p < .001), deductive reasoning was more prevalent in the second half (Z = 4.147, p < .001), and inductive reasoning showed an increasing, albeit insignificant, trend (Z = 1.869, p = .062) towards being more prevalent in second halves.

R2)   Each group's transcribed protocol was mean-split into early/late parts. The results indicated that every analysis comparison had the same directionality and approximate size in each split half as they did in the main analysis (**HS1a** and **HS1b**). Every analysis that was significant in the main result was also significant for each transcript part, and conversely every insignificant main analysis was also insignificant in each transcript part.

R3)   All main results were re-run by group to assess whether the results were driven by a subset of groups. Splitting by group reduces power, and therefore this analysis mainly sought to interpret reliability based on directionality of results (as opposed to significance levels). For abductive reasoning, all five groups replicated a declining effect from both the first to middle part (p-values ranging from .11 to .002) and from the first to last parts (p-values ranging from .078 to .0001). For deductive reasoning, both the increasing effect from the first to middle part (p-values ranging from .14 to .0001), and the declining trend from the middle to last part (p-values ranging from .91 to .08) were replicable in all five groups. For inductive reasoning, the increasing trend from the first to last part was found for all five groups, although always insignificant (p -values ranging from .91 to .06). Less consistent was the inductive increasing trend from the middle to last part, as one group displayed opposite directionality, and one group showed no difference at all.

R4)   In order to assess whether the main results could be replicated at a different grain size, a reasoning pattern analysis *within* episode parts was conducted. Given the low count of inductive reasoning, the interaction between abductive reasoning and deductive reasoning was investigated. For each episode part, the number of abductive-deductive (AD) versus deductive-abductive (DA) sequence patterns, in terms of the order of which the reasoning types first occurred, was counted. The three parts of the episodes differed significantly in their reasoning patterns ($\chi^2(2) = 17.43$, p < .001). Follow-up 2x2 chi-square analyses showed that the first part had more

AD than DA interactions compared to the middle part ($\chi^2(1)$ = 17.32, p < .001), but did not differ from the last part ($\chi^2(1)$ = 2.44, ns). Conversely, the middle part differed from the last part, displaying relatively more DA than AD interactions ($\chi^2(1)$ = 5.11, p < .03). These results were replicable with an episode mean split, again indicating that the first half of episodes displayed relatively more AD than DA interactions compared to the second half ($\chi^2(1)$ = 13.5.11, p < .03). Taken together, the main results appear to be extremely reliable and robust across episode splitting choices, transcript parts, groups, and choice of grainsize. The trending direction was almost uniformly the same in the reliability checks, although the lower N resulting from splitting the dataset did not always allow for significant results. The overall result is strong support for **HS1a** and partial support for **HS1b**.

To determine whether the groups were internally representative of reasoning in line with the hypotheses, all groups were analysed in relation to a) the overall proportions of reasoning types uttered and b) whether each group was overly dominated by any single person, and whether these persons displayed different reasoning patterns than expected.

- Of the 15 participants, 12 (80%) adhered to the same order in terms of proportions of reasoning. That is, most utilised deductive reasoning, followed by abductive and finally inductive reasoning. Deductive reasoning was most prevalent for all of the remaining 3 participants.
- To address the internal distribution in groups and whether the most active participant would skew the results, our analysis showed that the most active participant in each group contributed 49%, 48%, 41%, 49% and 57% of all group utterances, respectively, compared to a predicted 33% if all contributed equally, which is theoretical and not expected. Of these 5 participants, 4 adhered to the overall reasoning ordering (as reported above), while the remaining participant displayed an equal proportion of abductive and inductive reasoning (both at 18%).

Therefore, the reasoning proportion differences at the individual group level does not seem to interfere with the representativeness of the overall results.

Hence, from the above reliability tests, the observed reasoning patterns show a great robustness in the data.

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5.2.3   Interpretation of results

As the results of **HS1a** show, there is a significant concentration of abductive reasoning in the first parts of ideas. Hence, the finding is consistent with reviewed models of design activity that assumes an abductive stage to initiate instances of inference-making in design activity (March, 1976; Schön, 1991). **HS1b** was only partially supported but showed the expected direction, thus indicating deductive reasoning increases as an idea progresses. The exploratory question of the presence of inductive reasoning can be negatively answered in the sense that inductive reasoning is the least prevalent type of reasoning. Rather, the last parts of ideas were the most concentrated parts of deductive reasoning.

The surprising prevalence of deductive reasoning persisted throughout all idea parts (55–76%), while there was a significant concentration of abductive reasoning in the first parts. Pertaining to the theoretically proposed two-stage process involving abductive-deductive patterns (as presented in Section 3.2), the study found reasoning to follow a general abductive-deductive pattern, with only a few occurrences of inductive reasoning and all the while dominated by deductive reasoning across all parts of ideas. This abductive-deductive pattern is further addressed and explained in the following sections using qualitative analyses of idea generation data from the protocols.

The tests to determine any differences between groups with or without fully experienced participants, as well as across various robustness checks, did not reveal any variations of the reasoning patterns. Hence, the reasoning patterns across many different factors, including experience of participants, temporal placement in idea generation sessions and more, are very robust and follow abductive-deductive patterns.

Next, two examples are presented to illustrate the reasoning patterns identified from the protocol analyses. This is done by presenting coded data along with a description of the specific sequences of reasoning occurring in each one.

5.2.3.1   Example 1

Table 23 contains the first example, including descriptions of the code definitions used for the three reasoning types. The idea episode begins with

an abduction proposing a principle to reuse water (Code definition: "A hypothesis to account for what is desired or intended", refer to Table 13). Following this, a sequence of deductions occur that argue for why the specific principle is useful by specifying that it is possible to measure the effect of the idea (rows 2-8, Table 23; Codes: Row 2: "Prediction of result in a given frame", rows 3-7: "Explicating hypothesis by suggesting consequences", row 8: "Definitive and certain conclusion"). Next, the facilitator [F] expands the idea by abduction (rows 9-10), building on the initial principle and initiating a new aspect of the idea. This time inductive reasoning follows the abductive reasoning by the remaining group members in the form of an evaluation of the user experience based on personal preference (rows 11-13; Code: Rows 11-13: "Inferring about future courses of events"). A group member then proposes to re-contextualise the initial idea principle (rows 15-16), after which deductions determine the effect of the solution (row 17) and a statement (though not explained further) that postulates that an alternative purification method is possible (row 18). Finally, a deduction proposes the possibility of a new principle for reusing water (row 21). Picture 2 shows a screen dump from the recorded material from a group participating in Study 1.

Picture 2: Screen dump from the recorded material from a group participating in Study 1.

Row	Speaker	Segment	Idea code	Reasoning code
1	M	But maybe you could clean the water sufficiently from one to the other in a bathroom,	idea	abductive
2	M	so it's not so much about returning it for wastewater treatment	idea	deductive
3	M	and then all the way back into the infrastructure,	idea	deductive
4	M	but you take it [the water] from the shower to the toilet,	idea	deductive
5	M	to a degree that it doesn't create too much foam,	idea	deductive
6	M	because there are soap leftovers in, or whatever.	idea	deductive
7	M	If it just fills the toilet cistern…	idea	deductive
8	M	You could calculate it.	idea	deductive
9	F	Yes, it could be that you could make a closed circuit,	idea aspect	abductive
10	F	for every hotel room, right?	idea aspect	abductive
11	M	Yes, I like that.	idea aspect	inductive
12	R	Oh yeah, I mean, then it's your own filth you meet again, right?	idea aspect	inductive
13	R	You would rather want that, than someone else's.	idea aspect	inductive
14	F	Yes	idea aspect	
15	R	Yeah, and you could make another closed circuit in the kitchens,	idea aspect	abductive

16	R	or the laundry room or the spa.	idea aspect	abductive
17	M	Then it shouldn't transport so much water at the same time.	idea aspect	deductive
18	R	No, and it can be used, and you can make differentiated purification methods.	idea aspect	deductive
19	M	Yes	idea aspect	
20	R	And possibly you could, if you make the…, I don't know how.	idea aspect	
21	R	but then you could go from drinking water to showering water to kitchen water to cleaning water to toilet water	idea aspect	deductive
22	R	or whatever it could be, so it sort of goes down through, right?	idea aspect	

Table 23: Example 1 - Idea episode from protocols, translated into English for reporting.

Three immediate observations stand out in this idea episode. First, the example shows that reasoning types occur in a pattern using all three types – abductive, deductive and inductive. Second, concerning the evolution of the idea, all group members partake in the elaboration of the idea through different aspects. Third, there is an interaction between the different occurrences of reasoning, both between and within the same reasoning types.

5.2.3.2 Example 2

The second sample idea episode presented in Table 24 is an example of a purely deductive reasoning pattern. The episode starts by proposing an object (an exterior cover) without stating the desired outcome (Table 24, rows 1-2). Thereafter follows the desired outcome, implicitly stated by reference to a solution from the bio-card method (row 3). A deductive sequence then begins by reusing the structure and principle provided by the bio-card (rows 4-12).

Row	Speaker	Segment	Idea code	Reasoning code
1	V	*An exterior cover* [surrounding the hotel],	idea	deductive
2	V	that can easily be done.	idea	deductive
3	V	But well, it absorbs the dew…	idea	deductive
4	V	It's kind of like a membrane within a membrane, okay.	idea	deductive
5	V	So the membrane has these small channels,	idea	deductive
6	V	I mean, it leads the water in these tiny channels,	idea	deductive
7	V	just like the desert rhubarb.	idea	deductive
8	V	Then there are simply these rhubarb leaves forming a surface,	idea	deductive
9	V	then the tiny channels leads the water,	idea	deductive
10	V	and then they [water channels] can lead to some small, local water reservoirs,	idea	deductive
11	V	then it doesn't have to lead it to a large reservoir in the ground,	idea	deductive
12	V	so it will be small local water reservoirs.	idea	deductive

Table 24: Example 2 - Idea episode from protocols, translated into English for reporting.

The example shows that reasoning patterns including only deductive reasoning are possible, in this case by analogising from a commonly

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understood object (the bio-card solution) towards a solution. Hence, the method card provided a kind of placeholder argument or reasoning pattern that framed the ideas, leading to a purely deductive pattern. This resembles the kind of deductive sequences found by Galle (1996b), showing deductive reasoning can lead to new discoveries. Also observed from the example is the absence of abductive reasoning and that only one person contributes to the idea.

Abduction-coded segments tended to occur in an uncertain form that at the same time proposes new frames or perspectives on functions to achieve in order to address the design task with saving water. The frames are not absolute and are observed to change as the idea progresses through re-framings that propose new problem settings and aspects of ideas (Dorst & Cross, 2001; Schön, 1991). Concretely, Example 1 shows how a first abduction is made (Table 23, row 1) in which a specific perspective that can possibly lead to the saving of water is introduced. Later in the same example, abductions occur again to re-frame the initial perspective (rows 9-10) and again later introduce a sub-function to the previous perspective (rows 15-16).

Deduction-coded segments functioned to derive effects in response to the frames and appear as causal inference chains. Often, these deductions drew on previous abductive reasoning as the premise. Further, they did not produce guaranteed objective 'truths' by a logical definition (Peirce, 1980). Rather, the deductions serve to explore and concretise the framing to amend and discern the validity of the abduction (Johnson-Laird, 2009; Schön, 1991). The two examples each provide an explanation for the high proportion of deductive reasoning found in the protocols. Example 1 shows that deductive reasoning could occur as a series of deductions functioning to describe a solution (Table 23, rows 2-8) to a prior abduction (row 1), which is similar to a verbal form of mental simulation, a strategy for resolving uncertainty in design activity (Christensen & Schunn, 2009). Example 2 shows a different deductive reasoning sequence (Table 24) that involves the analogical mapping of a solution provided by the bio-card design method to the design task at hand. This can be interpreted as an instance of direct analogical transfer (Ahmed & Christensen, 2009), a strategy mostly used by novice designers (ibid.). However, the example also overlaps with the notions of

explanatory abductive reasoning (Roozenburg, 1993) and abduction-1 type reasoning (Dorst, 2011) in that the reasoning pattern (here coded as deductive) follows an implicit abductive explanation that uses a known solution in a new context, resulting in a causal explanation.

Induction-coded segments are shown in Example 1 to occur in the form of informal appraisal of an idea, whether in the example as personal preference (Table 23, row 11) or as a combination of evaluating the consequence of an idea and personal preference (rows 12-13). However, these are not instances of reasoning suitable for evaluation in relation to the discussed models of design and the formal role of inductive reasoning as the generalisation of the specific to the general (Peirce, 1980). Rather, the empirical analysis of inductive reasoning implies that for inductive reasoning, the expression of personal preference (e.g., the utterance "Yes, I like that" found in row 11, Example 1) is part of a verbal form of some underlying acceptance of what was previously proposed. This acceptance is based on some previous knowledge or experience or even attitude towards a specific idea. However, since the reasoning is argumentative, it holds a possible importance to the dialogue as it promotes a positive attitude and agreement that might spur the continuation of other members of a group.

However, despite the negligible role of inductive reasoning, it is contended that the observed abductive-deductive patterns (discussed at length in Section 5.2.4) in part compensate for the lack of evaluation through mental simulation (Christensen & Schunn, 2009). That is, for deductive reasoning, the utterances put forward (often in sequences) that are assumed to 'explicate' and explore an insight from the premise provided one possible consequence of a premise (or frame). Thus, this one possible solution is not without importance, since it would continue to be one of the more relevant solutions to a proposed frame (assuming that uttered ideas are better than ideas never put forward by anyone in a team). In turn, such a solution would then satisfy the need for exploring a given frame, simulating and evaluating an idea. Indeed, similar studies of design reasoning have found deductive reasoning to be evaluative (Dong *et al.*, 2015) in relation to ideas.

5.2.4   Discussion of results: Reasoning patterns and proportional distributions

The following paragraphs discuss the reasoning types and patterns using specific occurrences from the above presented examples and outline the implications of the results for the research.

From the results of the tested hypotheses and the observations made from idea episodes, three arguments and their implications are put forward. The first states that abductive-deductive sequences are a central component of micro-level design activity. The second proposes that the reasoning types identified at the micro-level of design activity are not the same as those identified from a logical notation as initially proposed by Peirce (1980) and widely used to describe design reasoning (see e.g., Dorst, 2011; Roozenburg, 1993). Rather, empirically analysing reasoning necessitates perceiving reasoning patterns unlike those proposed in conceptual proposals of reasoning in design. These are argumentative and thus carry a performative element in that the verbal reasoning acts to frame later responses (i.e., the behaviour) and thus enact design activity (Dong, 2007). Third, verbal reasoning is indicative of the mental models and beliefs held by individuals.

5.2.4.1   *Abductive-deductive patterns dominate design idea generation*

As observed from the analysis of the proportional distribution of reasoning and tested by the hypotheses, an abductive-deductive pattern is appropriate for describing design activity in a context of idea generation, similar to what Roozenburg and Cross (1991) describe as *analysis-synthesis* cycles, or as operation between concept and knowledge domains, as proposed by C-K theory (Hatchuel & Weil, 2008). As such, the reasoning types enter into patterns of inference that interact between abductive reasoning, found to be significantly concentrated at beginning of ideas, and deductive reasoning that is concentrated in later parts of ideas, but dominant throughout. Abductive reasoning proposes frames or perspectives for addressing the main design task, while deductive reasoning in turn explores how such a frame is viable to actually address the design task by simulating action and thus determining the validity of solutions (Johnson-Laird, 2009; Lloyd & Scott, 1994). This process then repeats, resulting in variations of the original frames, as exemplified by Table 23, rows 1-10. Hence, abductive-deductive cycles of reasoning without any explicit inductive reasoning to evaluate are

not indicative of aimless activity. Rather, the cycles display similarities to what several models of design propose as a core tenet to design – the ability to quickly iterate between phases that are divergent and convergent, whether defined as mental simulation (Christensen & Schunn, 2009), generative sensing (Dong *et al.*, 2016) or composition and decomposition (March, 1976). Aside from determining the presence of such patterns empirically, the study shows how different reasoning types interact and are interdependent, as further discussed below.

5.2.4.2 *Micro-level design activity contains interactions between reasoning types*

The applied coding scheme identifies reasoning patterns at a micro-level of design activity and enables description of the small steps of reasoning involved in generating ideas. While a prominent abductive-deductive pattern exists, the presented examples of idea episodes show how reasoning types occur in chains of reasoning in different types and in disorderly patterns that do not necessarily adhere to formal reasoning types. These interactions between reasoning types further show that each individual instance of reasoning is interdependent on the other instances in which it is put forward, whether or not it be from the same person. Hence, a micro-level analysis of reasoning like this then improves understanding of design activity (Rittel, 1987) by showing how the different reasoning types interact by drawing conclusions using different patterns of inference. For example, this can take the form of the use of deductive reasoning to arrive at a solution under a given framing or the use of inductive reasoning to evaluate a framing with no presence of deductive reasoning. Such observations imply that design activity does not follow a strictly logical form, but instead is informal and comprises un-structured and opportunistic activities (Ball & Ormerod, 1995). These activities are shared, resembling the concept of shared cognition (DeChurch & Mesmer-Magnus, 2010) or team mental models (Dong *et al.*, 2013), which are indicators for the ability of groups to successfully work together.

The analysis method applied in the research is based on the proposal that micro-level, argumentative reasoning is key to understanding design activity (Rittel, 1987). While other reviewed studies of design reasoning have applied different methodologies, interpretations of reasoning and/or unit of analysis

(e.g., Dong, Lovallo, & Mounarath, 2015; Galle, 2002; Lloyd & Scott, 1994), the analysis method here is not seeking to replace such above-mentioned methods. Rather, this approach allows for a different perspective on reasoning in idea generation specifically. The micro-level analysis of design reasoning offered here has the advantage of capturing reasoning as it is actually put forward to other members in a design team but is limited in that it does not capture implicit, common understandings in a team. The research method thus offers an alternative, empirically founded interpretation of reasoning in design activity that is in contrast to existing conceptual models of design reasoning (Dorst, 2011; March, 1976; Roozenburg, 1993) as well as other empirical studies of reasoning (Galle, 1996a; Lloyd & Scott, 1994).

5.2.4.3 *Verbal reasoning is argumentative*

Acknowledging that verbal reasoning is influenced by values and intentions (Roozenburg, 1993; Stumpf & McDonnell, 2002) and that verbal reasoning is a process of argumentation (Rittel, 1987) that enacts design and thus influences design activity (Dong, 2007), the reasoning analysed here is inherently subjective and non-monotonous (McDonnell, 2012). This implies that while one participant in a group design activity may use deductive reasoning because an inference fits a mental model held, the same inference may not be 'true', and thus not suitable for deductive inference, in the group mental model, or with another participant. Therefore, reasoning used during group design activity has a dual function of both making inferences toward the generation of new ideas and is also indicative of the mental models held by the members of that group, whether or not they are shared by other group members. Hence, reasoning is argumentative, highlighting the importance of the performative aspect of verbal reasoning when empirically analysing design activity. The notion of performativity is investigated and discussed further in the next section by analysing whether initial framings of ideas influence how ideas further develop.

Following the first analysis of Study 1, it is concluded that:

- It is possible to reliably identify reasoning patterns from micro-level segments in group idea generation activity. The results are furthermore very robust across different means of analysis.
- The three fundamental reasoning types are markedly different from the logical inferences they are presented as in most related research on reasoning in design activity, and reasoning is highly dependent on entering into chains of inference with other occurrences of reasoning.
- There is empirical evidence for the conceptually proposed two-stage processes of reasoning following abductive-deductive patterns. Such patterns are critical to design activity in idea generation, whereas the importance of inductive reasoning seems less important in idea generation activity.
- Reasoning patterns, as identified at the micro-level from verbal data between members in a group, are disorderly and do not adhere to the above patterns at the individual idea-episode level.
- The reasoning from empirical, verbal data is argumentative, representing a performative aspect of design activity and indicative of underlying mental models or beliefs held by those uttering the reasoning.

Next, the focus is turned to the analysis of the relationship between reasoning patterns and problem-solving behaviour.

5.2.5 Reasoning patterns and relation to problem-solving activity and behaviour

This section addresses the overall research issue of correlating reasoning patterns to problem-solving behaviour in design activity and gauging the relation of reasoning patterns to the interrelation of design moves that are indicative of creative quality (Gruber, 1980). To reiterate, problem-solving behaviour is here interpreted as the combination of breadth and depth moves.

Hence, the focus here is on applying the identification of reasoning patterns, as established in the above, and relating the patterns to other characteristics of design activity, such as the creative behaviour demonstrated. As in the previous set of results, the qualitative analyses of the protocols are used to make observations and relate to the actual data.

A first set of hypotheses predicted the short-term effect of reasoning patterns (within design moves) in the immediate idea episode:

HS1c:

Design moves started by abductive reasoning are more likely to be breadth moves than those initiated by deductive reasoning.

HS1d:

Moves containing abductive-deductive interactions are more likely to be breadth moves than those with no such interactions.

A second set of hypotheses predicted the longer-term effect of reasoning patterns (across idea episodes) when new idea themes are generated in the following idea episodes:

HS1e:

Initial moves started by abductive reasoning result in the theme being more prevalent than moves begun by deductive reasoning.

HS1f:

Initial moves containing abductive-deductive interactions result in the theme being more prevalent than moves with no interactions.

HS1g:

As the number of depth moves following an initial move increases, so will the prevalence of the introduced theme increase.

Quantitative results from protocol coding

Below, the coding results are presented to provide an overview and basis for the following hypothesis testing. To illustrate the coding scheme, an example is presented.

Coding step A: As also reported earlier, a total of 217 *ideas* and 258 *idea aspects* were identified across the five groups. This totals 475 design moves. **Coding step B1:** Of the 475 design moves, 257 (54.1%) were *breadth* moves and 218 (45.9%) were *depth* moves. Table 25 presents the numbers across the groups.

Group	1	2	3	4	5	Total
Idea	44	53	42	37	41	217
Idea aspect	64	49	49	65	31	258
Design move	108	102	91	102	72	475

Table 25: Number of ideas and idea aspects generated across the five groups, as determined by coding steps A and B1.

Coding step B2: Of the 475 design moves, 217 (45.7%) were *initial moves* (not to be confused with the count of ideas in coding step A), signifying that a theme appeared for the first time in a group. While it may be expected that each idea started a new theme, this was not the case, and new themes appeared in both *idea* and *idea aspects*, as well as breadth and depth coded design *moves*. Each theme appeared in 3.77 *moves* on average (range = 1-11, SD = 2.89). Table 26 shows the distribution of *initial moves* across the types of design moves: *idea, idea aspect*, *breadth* and *depth*.

	Type of design move	Count	Percentage
Initial move (of a theme)	Idea	106	48.8%
	Idea aspect	111	51.2%

| | Breadth | 130 | 59.9% |
| | Depth | 87 | 40.1% |

Table 26: Distribution of initial moves across the variables of idea and idea aspect and breadth and depth moves.

The results presented in Table 26 indicate an almost equal distribution between whether new themes first occur in either an idea or idea aspect (48.8% vs. 51.2%), as well as a fairly equal distribution between breadth or depth moves (59.9% vs. 40.1%). This shows that new themes in the idea generation process stem from moves that are practically irrespective of design move classification, and thus originating types of behaviours (breadth or depth) implying that problem-solving activity in idea generation does not follow top-down breadth-first approaches, as also found by Ball & Ormerod (1995).

Coding step B3: As reported earlier, the protocols resulted in 5.792 segments of which 1.698 (29%) were coded for the presence of reasoning. Table 27 summarises the distribution of reasoning to start the 475 moves identified in coding step A and shows that deductive reasoning is the most frequent reasoning type used to start moves, accounting for 55.4% of all reasoning occurrences.

		Abductive	Deductive	Inductive
Reasoning start	Count	169	263	43
	Proportion	35.6%	55.4%	9.1%

Table 27: Counts and proportions of reasoning types used to start moves, as determined by coding step B3.

The analysis of abductive-deductive patterns found critical to design activity in the previous analysis (Section 5.2.1) was done automatically from the protocols and yielded 191 moves (40.2%) containing interactions, whereas 284 moves (59.8%) did not. An abductive-deductive pattern means that the two reasoning types occur in sequence within an idea episode, no matter the order.

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Next, an example illustrates the new coding scheme introduced to the analysis.

Protocol data			Coding steps			
Row	Spe aker	Utterance	A	B1	B2	B3
1	A	So what if you, I just wondered,	idea	abductive		
2	A	what if they had like a light,	idea	abductive		
3	A	so they could see how the water was used in the building,	idea	abductive		
4	A	could the hotel use that for anything?	idea	abductive		
5	A	I mean to have better service	idea	deductive		
6	A	or to see when the different rooms need cleaning, or…	idea	deductive	Breadth	Visualisation of water consumption
7	B	I just thought of this like,	idea aspect 1			
8	B	some displays where you press, for example	idea aspect 1	deductive		
9	B	so if you hold your finger on the button when you flush,	idea aspect 1	deductive		
10	B	I mean, then it was green and then it was…	idea aspect 1	deductive		
11	B	And then, no more	idea aspect 1	deductive		
12	B	You could make a digital app…	idea aspect 1	abductive	Depth	Visualisation of water consumption
13	C	You can also electrify it,	idea aspect 2	abductive	Breadth	Behaviour

14	C	that creates an instant effect.	idea aspect 2	deductive		
15	C	You get a shock.	idea aspect 2	deductive		
16	D	If you hold it too long, then…	idea aspect 2	deductive		
17	D	That's also what I'm thinking, eh	idea aspect 2			
18	D	to put a timer in the shower,	idea aspect 2	deductive		
19	D	so after two minutes…	idea aspect 2	deductive		
20	D	not like it runs out of hot water,	idea aspect 2	deductive		
21	D	it can't, that annoying.	idea aspect 2	inductive		
22	C	Yeah, you need to do something	idea aspect 2			
23	D	Yes, or just like with the two minutes, or something like the…	idea aspect 3			
24	D	then you get a cold shock,	idea aspect 3	deductive		
25	D	and then it gets hot again,	idea aspect 3	deductive		
26	D	just like a wakeup call,	idea aspect 3	deductive		
27	D	so now you have…	idea aspect 3	deductive	Depth	Behaviour change

Table 28: Example 3 – Idea episode from protocols, translated into English for reporting.

5.2.5.1   Example 3

Table 28 shows an example from the protocols including codes and allows for making qualitative observations with regards to the data.

Table 28 presents an example of an entire idea episode from the protocols. The specific example shows the initial presentation of the idea (Table 28, rows 1-6), followed by three different aspects (rows 7-12, 13-22 and 23-27) totalling four design moves (column A). Of these, two are breadth moves and two are depth moves (column B1). Similarly, the coding established two different themes covered by the idea (column B2). Finally, the reasoning types for each segment are shown (column B3). To further interpret the coding scheme results, two observations from the example are useful.

First, the content of the dialogue starts with a desire to visualise water consumption (rows 1-12), after which the focus shifts to changing the behaviour of a person (the hotel guest) using a toilet (rows 13-27). Hence, the overall idea episode shown in the example contains shifts between breadth and depth moves and also cover more than one theme. As also shown in the example, abductive reasoning starts with both breadth moves (rows 1-4, and row 13 respectively). Second, there are instances of abductive-deductive interaction present, for example in rows 1-6, functioning to bridge an initial framing (abductive) towards concrete solutions (deductive).

5.2.6 Testing the short-term effect of reasoning patterns on problem-solving behaviour

To test **HS1c** and **HS1d**, a binomial logistic regression was performed (refer to Table 29) to ascertain the effects of reasoning type on starting design moves and the presence of abductive-deductive patterns. The test controlled for group and idea generation method, based on the likelihood that a design move is breadth orientated compared to depth. In all, 432 (90.9% of total) moves qualified as being started by either abductive or deductive reasoning and were included in the model. The logistic regression model was statistically significant, $\chi^2(8) = 38.255$ p < .001. The model explained 11.4% (Nagelkerke R^2) of the variance in breadth vs. depth moves and correctly classified 60.8% of cases. Both the predictor variables, reasoning type beginning design moves and the presence of abductive-deductive interactions, were statistically significant. Neither of the two control variables, group and idea generation method, were statistically significant. **HS1c** was supported with the result that moves started by abductive reasoning were 2.943 times more likely (p < .001) to be breadth

moves compared to moves started by deductive reasoning. **HS1d** was supported by the result that moves containing abductive-deductive interactions were 1.820 times more likely (p = .026) to be breadth moves compared to moves containing no such interactions.

	B	SE	Wald	df	Sig.	Odds ratio
Initial type of reasoning	1.080	.227	22.596	1	p < .001	2.943
Abductive-deductive interaction	.599	.269	4.957	1	p = .026	1.820
Group	-	-	8.596	4	p = .072	-
Idea generation method	-	-	.646	2	p = .724	-
Constant	-.134	.333	.161	1	p = .688	.875

Table 29: Binomial logistic regression predicting the likelihood of breadth vs. depth moves based on type of reasoning starting the move and the presence of abductive-deductive interactions, controlling for group and idea generation method. Note: Initial type of reasoning is for abductive reasoning compared to deductive, and the abductive-deductive interaction is for present compared to not present.

The results showed that moves initiated by abductive reasoning as well as moves containing abductive-deductive patterns are predictive of breadth moves, in support of **HS1c** and **HS1d**. Both tested reasoning patterns had significant short-term effects on design activity. The strongest effect was observed for the reasoning type used to start the move, while the presence of abductive-deductive reasoning patterns was smaller.

Abductive reasoning predicts breadth moves that hypothesise lateral moves in a design space focusing on the problem or purpose in a context of design idea generation. Abductive-deductive patterns were also predictive of breadth moves and thus hold a similarity to 'designerly' activity (Roozenburg & Cross, 1991) in the sense that new possibilities for solutions are proposed. In contrast, moves framed by deductive reasoning and with no abductive-deductive interactions are more likely to be depth moves, indicating that such moves are akin to being simulations (Christensen & Schunn, 2009) or explorations of the consequences of preceding breadth moves (Fann, 1970).

5.2.7 Predicting the longer-term effects of reasoning patterns on the prevalence of themes in later idea generation activity

To test hypotheses **HS1e**, **HS1f** and **HS1g**, a Poisson regression was used (refer to Table 30) to predict the number of later occurrences of a theme from the time it initially occurred based on the type of reasoning to start the corresponding move, the presence of abductive-deductive interactions and the number of aspects present in the idea episode, controlling for group and idea generation method. A total of 199 (41.9% of total) moves qualified as initial moves, were started by either abductive or deductive reasoning, and were included in the model. The Poisson regression model was statistically significant, $\chi^2(9) = 63.190$ p < .001. **HS1e** was not supported, as the reasoning type used to start the move was not statistically significant (p = .681). **HS1f** was validated by the result that for themes in moves containing an abductive-deductive interaction, a theme appeared 1.866 times more often (p = .002) later in the idea generation process compared to moves not containing an abductive-deductive interaction. **HS1g** was sustained by the result that for every depth move following the move in which a theme first appeared, the theme appeared 1.201 times more often (p < .001) later in the idea generation process. The group control variable was not statistically significant (p = .450), while the idea generation method control variable was statistically significant (p < .001). The latter result was to be expected since all groups started by using the brainstorm idea generation method, resulting in more themes occurring initially during this phase.

	B	SE	Wald	df	Sig.	Odds ratio
Intercept	-.451	.2633	2.932	1	p = .087	.637
Initial type of reasoning	-.056	.1358	.168	1	p = .681	.946
Abductive-deductive interaction	.624	.2006	9.673	1	p = .002	1.866
Group	-	-	3.688	4	p = .450	-
Idea generation method	-	-	15.646	2	p < .001	-
Number of aspects following	.183	.0520	12.414	1	p < .001	1.201

Table 30: Poisson regression predicting the number of times a theme re-occurs after being initially mentioned based on type of reasoning to start move, the presence of abductive-deductive interactions, the number of depth moves following, and controlling for group and idea generation method. Note: Initial type of reasoning is for abductive reasoning compared to deductive, and abductive-deductive interaction is for present compared to not present.

Hypothesis **HS1e** was not supported as there was no significant result between reasoning used to frame moves and the later prevalence. This was surprising, as it was expected that moves started by lateral thinking would assist the initiation of themes that offered new perspectives on the design task and thus result in more prevalence in later moves, a long-term version of the framing effect proposed by Darke (1979). One possible explanation is the level of aggregation from an initial utterance of a certain type of reasoning to the influence over several moves later in the idea generation process. This further implies that the initial framing of ideas is not a significant means by which to determine (i.e., frame) subsequent design activity. However, **HS1f** was supported, showing that abductive-deductive interactions are predictive of a theme's influence on the idea generation process. Hence, this result further supports the conclusion from the previous analysis by showing the importance of abductive-deductive interactions. Finally, **HS1g** was supported, indicating a relationship does exist between

increased level of detailing after a new theme is initially introduced and the prevalence of that theme in later moves.

5.2.8 Discussion of results: Reasoning patterns and problem-solving behaviour

This discussion first focuses on the influence of reasoning types on problem-solving approaches through the relationship between reasoning patterns and breadth and depth approaches to problem solving. It discusses the two concepts for inferring quality and creativity in idea generation through the lens of reasoning patterns and design moves, interpreted as short- and long-term effects of reasoning patterns. Finally, the section discusses the implications of and further questions raised by the study.

5.2.8.1 Predicting the short-term effects of reasoning patterns

The support for hypotheses **HS1c** and **HS1d** implies that reasoning patterns are a viable means of characterising designer behaviour that predicts breadth and depth orientations when generating ideas. Pertaining to the first research issue of how reasoning patterns involving abductive and deductive reasoning influence breadth and depth moves, the results show that there is indeed a relationship. Abductive reasoning promotes thinking that orients idea generation activity laterally towards focusing on new frames and perspectives for addressing a problem. In contrast, the absence of abductive reasoning, and thus a convergence on deductive reasoning, promotes linear thinking that simulates and explicates possible solutions as a response to a set frame. Despite related research describing abductive framing and lateral thinking as core to design activity (Osborn 1953; Roozenburg 1993; Dorst 2011), these results show that a dynamic between abductive and deductive reasoning is necessary since the coding found a fairly even distribution between breadth and depth moves in the protocols. While activity associated with abductive reasoning aligns with notions of creativity, deductive reasoning and depth moves not only serve to react to some already given fact or as pure logical reasoning (Peirce, 1980). On the contrary, the analysis showed that depth moves serve to initiate a substantial part of new themes in the idea generation process. Hence, the results suggest that deductive reasoning and depth moves influence the idea generation process by exploring consequences, frames and ways of addressing a design task (Atman *et al.*, 2005), which is an important part of

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dealing with uncertainty and providing tentative answers in design activity (Christensen & Schunn, 2009). The evaluative aspect of deductive reasoning is also discussed in Section 5.2.4.

The present study involving experienced designers found depth moves to be almost as frequent as breadth moves (45.9% vs. 54.1%), lending support to the argument that the use of depth moves serves a dual purpose of both allowing to learn about a problem in response to abducted frames and offering perspective (Christensen & Schunn, 2009). Still, it is also indicative of a lack of expertise in a specific domain. This is due to a need for actively explaining a concept, for example, the need to proceed with a deductive reasoning sequence to simulate and explore the consequences of an idea or concept, which is related to the behaviour of novice designers (Ahmed-Kristensen & Babar, 2012), indicating a lack of existing knowledge. In a context of group idea generation, these deductive patterns also occur in the form of 'thinking out loud' (as mental simulations) to the other participants or as explaining a known concept or solution to other participants in the process. This is representative of the argumentative aspect of reasoning (see Section 5.2.1, Example 2, Table 24) in which an idea is produced in a deductive form by use of analogy. Similarly, when an idea is uttered in an entirely deductive form, it could be indicative of a known idea (to the person arguing), thus not requiring any reasoning other than deductive because a mental model can be run.

5.2.8.2   *Predicting the long-term effects of reasoning patterns*

Combined, the results of hypotheses **HS1e**, **HS1f** and **HS1g** find that in the genesis of new themes in idea generation, two behaviours positively influence the later prevalence of said themes. Thus, the research issue concerning the influence of design behaviours in the genesis of themes that become influential on creativity in the idea generation process is addressed and answered in the following. The first influencing behaviour pertains to the combination of abductive and deductive reasoning, the second being the detailing of the theme in the design moves immediately following. Despite the type of reasoning used to frame moves, **HS1e** was not found to significantly influence the number of later moves. The significance of abductive-deductive interactions in combination with depth moves to detail and explicate provides an empirical demonstration that balancing framing

and detailing activity is indicative of 'good' behaviour in design activity (Atman *et al.*, 2005; Valkenburg & Dorst, 1998), in the sense that the move influences later activity. Such behaviour is likely to lead to the later accumulation and interrelation of moves indicative of creativity (Goldschmidt & Tatsa, 2005; Gruber, 1980).

In summary, the results show that the characteristics of reasoning patterns influence idea generation in the following ways:

- Initially in ideas, the type of reasoning used for framing is key to how an idea develops **(HS1c)** as the strongest predictor (compared to the presence of abductive-deductive interactions – **HS1d**) of whether moves are breadth or depth based.
- After an idea episode ends, the framing effect of the initial reasoning types used fades (**HS1e**), while the presence of abductive-deductive interactions (**HS1f**) and a detailing of ideas (**HS1g**) become stronger predictors of the propagation of idea themes.
- Throughout, the presence of abductive-deductive patterns have significant influence on design activity.

5.2.8.3   *Reasoning patterns and creativity*
By showing the significant effects of reasoning patterns and breadth and depth moves in design activity, the study contributes empirical evidence for how the presence of abductive-deductive dynamics in generating ideas is a basis for a higher degree of interrelatedness and thus creativity. Creativity is used here in the sense that the results empirically demonstrate how the reasoning patterns influence the later activity in idea generation processes.

The results imply that while abductive reasoning is central to the proposal of novel frames and ways to address and evolve problems, deductive reasoning plays a similarly central role to design activity by explicating and detailing solutions to the above frames. The implication is that themes are results of abductive reasoning in combination with depth moves. The discussion brings to bear the argumentative and intentional aspect of design activity as it unfolds between stakeholders with varying values and perspectives (Bucciarelli, 2002), and further accentuates the performative role of reasoning and its effect on design activity (Dong *et al.*, 2013).

Further, the analysis provides the foundation for developing a method to describe design activity that allows for inferring creative behaviour in processes with no need to assess or otherwise measure outcome products or idea representations. Hence, the analysis focuses on the micro-level aspects of design activity through the lens of reasoning (Rittel, 1987). This approach has thus proven it feasible to describe micro-level inferences that influence design moves as well as the later accumulation of moves, resulting in an improved description and understanding of design activity. The analysis method presented is useful in addressing the desire to provide means to concurrently diagnose and control design activity. Further work to verify the results of the present study could involve comparing reasoning patterns and design move characteristics to how ideas are assessed. Such analyses would further enhance prediction of the influence of specific design behaviour on how ideas are evaluated and be valuable to the downstream design process following initial idea generation.

To summarise, the second analysis of Study 1 concludes that:

- The analysis of reasoning patterns is a viable means by which to predict whether design moves are breadth or depth orientated as part of a problem-solving behaviour. This allows the coding scheme for reasoning types to be applied to characterising problem-solving behaviour.
- The presence of abductive-deductive reasoning patterns is again confirmed to have a significant effect on design activity in idea generation, both short- and long-term. Compared to the previous analyses, the analysis conducted in this section shows how the abductive-deductive pattern tends to signify breadth moves, and that such moves are also more likely to influence the themes of ideas generated later in the process.
- The initial framing of a design move can significantly predict a short-term problem-solving orientation, suggesting the importance of the type of reasoning used to propose new ideas and themes. However, the same initial framing of design moves cannot predict whether a theme is more prevalent over time in idea generation activity, indicating that the initial framing effect is not strong enough to influence the design activity appearing later.
- The coding scheme for reasoning provides a means of diagnosing and implying creative behaviour in problem-solving activity without involving external measures, such as an evaluation of ideas that is only done *post* idea-generation activity.

5.3 STUDY 2 - SMART

This section contains the results of Study 2 - SMART. As mentioned earlier, the study addresses the research issue:

Using reasoning patterns taking place when generating an idea to predict how that idea is later evaluated to be valuable.

5.3.1 Coding results

Table 31 summarises the total number of evaluated ideas and their distribution across the four categories. The table also contains the mean amount of reasoning and proportion of abductive reasoning for each category.

Company	A	B	C	D	Average
Number of ideas	47	68	102	76	73.25
Mean amount of reasoning	20.3	7.4	6.4	7.7	9.2
Mean proportion of abductive reasoning	11.8%	19.1%	13.6%	10.5%	13.8%

Table 31: Number of ideas and reasoning pattern characteristics for each company

As the results show, the numbers of ideas differ, especially for Company A, who generated fewer ideas (47, vs. 68-102 for the other companies). However, Company A had a much higher average amount of reasoning (20.3 vs. 6.4-7.7 for the other companies) in ideas, indicating fewer, but more elaborated ideas. As for the proportion of abductive reasoning, Company B stands out (19.1% vs. 10.5-13.6% for the other companies). These results are explored at length in the following paragraphs.

Idea evaluation

A total of 370 sticky notes were evaluated, of which 293 (79.2%) could be mapped to the protocols with certainty. This is a result of the study design as the sticky notes produced by the participants were not placed in an evaluation category until later (refer to the procedure description in Section 4.5.2). Table 32 presents the distribution of ideas into the evaluation categories. The sticky notes excluded from the analysis showed a similar

distribution of evaluation categories to those included; therefore, no particular pattern of any one category was omitted that could otherwise potentially distort the analysis results.

	Reject	Put on hold	Analyse	Accept	Total
Count	44	41	40	168	293
Percent	15%	14%	13.7%	57.3%	100%

Table 32: Count and distribution of idea evaluation categories.

The results show an even distribution of the categories *reject*, *put on hold* and *analyse* together accounting for 42.3% of all evaluated ideas, while *accept* ideas accounted for the remainder. Hence, the majority of generated ideas were deemed valuable to the ongoing product development process.

5.3.2 Reasoning start to episodes

The hypothesis regarding the effects of reasoning type on initiating ideas and the effects of idea evaluation was tested.

HS2a:

Idea evaluation is dependent on the use of deductive or abductive reasoning to initiate idea episodes.

A chi-square test of independence was conducted between the reasoning type sparking ideas (abductive or deductive) and evaluation of the idea. Note that inductive reasoning was excluded from the analysis since the initial test (Cramer-Petersen & Ahmed-Kristensen, 2015) and the frequencies of the study reported found only very few instances of inductive reasoning initiating ideas (for the full report, see Table 34 below). The association was statistically significant, $\chi^2(3) = 26.705$, $p < .0001$, and strong, Cramer's V = .309 (Cohen, 1988). The result supports **HS1a** and is further described in Table 33 along with the counts, expected counts and the adjusted residuals of the chi-square test.

		Idea evaluation				
Reasoning type		Reject	Put on hold	Analyse	Accept	Total
Abductive	Count	15	24	19	38	96
	Expected count	14.1	13.1	13.1	55.7	
	Percentage deviation	6%	83%	45%	-47%	
Deductive	Count	26	14	19	124	183
	Expected count	26.9	24.9	24.9	106.3	
	Percentage deviation	-3%	-78%	-31%	17%	
Total	Count	41	38	38	162	279

Table 33: Results of chi-square test of independence between reasoning type used to initiate ideas and evaluation of the idea.

As the table shows, abductive reasoning at the start of ideas was more frequent for ideas that were later evaluated as *put on hold* and *analyse* categories. Calculating from the actual count versus the expected count, the test found 83% more ideas *put on hold* and 45% more ideas in *analyse* than expected. *Accept* category ideas were less common, as the test found 47% fewer ideas in this category than expected. Since the test only included abductive and deductive reasoning types, the trends are reversed for deductive reasoning, albeit with different percentages because of varying proportions due to greater numbers of occurrences of ideas starting with deductive reasoning. The clear pattern is that ideas that are evaluated as potentially useful and more radically different from existing ideas are more likely started by abductive reasoning. Conversely, ideas accepted for further work are more likely started by deductive reasoning.

To further investigate the reasoning types used to start ideas, another chi-square test of independence was conducted (Table 34) between reasoning type initiating ideas (abductive, deductive or inductive) and the proportion of the reasoning occurring in the protocols (i.e., the proportional occurrence

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of a reasoning type to start an idea compared to its prevalence in the protocols). There was a statistically significant association, $\chi^2(2) =$ 169.874, $p < .0001$, which was moderately strong, Cramer's V = .225 (Cohen, 1988).

		Reasoning occurrences		
Reasoning type		First reasoning	Not first reasoning	Totals
Abductive	Count	125	310	435
	Expected count	48	387	
	Percentage deviation	161%	-20%	
Deductive	Count	227	2245	2472
	Expected count	273	2199	
	Percentage deviation	-17%	2%	
Inductive	Count	18	429	447
	Expected count	49	398	
	Percentage deviation	-64%	8%	
Total	Count	370	2984	3354

Table 34: Results of chi-square test of independence between reasoning type to start ideas and the total proportion of the reasoning type.

As the table shows, there is a 161% higher occurrence of abductive reasoning to start ideas and a 64% lower occurrence of initial inductive reasoning than expected from the test. This result indicates that abductive reasoning is commonly used to start ideas, which makes sense as beginning with abductive reasoning predicts breadth moves (refer to Section 5.2.5) and because abductive reasoning generally frames new ideas.

5.3.3   Idea evaluation categories

Next, the second set of hypotheses was tested concerning the use of reasoning patterns to predict idea evaluation. To re-iterate the idea

evaluation categories, Figure 8 is repeated here (also presented in Section 4.5.2) to show the dimensions against which each idea was evaluated and how the placement in the matrices resulted in idea evaluation.

MATRIX 1

Fit to on-going project

HIGH

REJECT   MOVE MATRIX 2

LOW

REJECT   PUT ON HOLD

LOW

Value to customer/user   HIGH

MATRIX 2

Value to company strategy

HIGH

ANALYSE   ACCEPT

HIGH

REJECT   ANALYSE

LOW

Risk, complexity and/or development effort   LOW
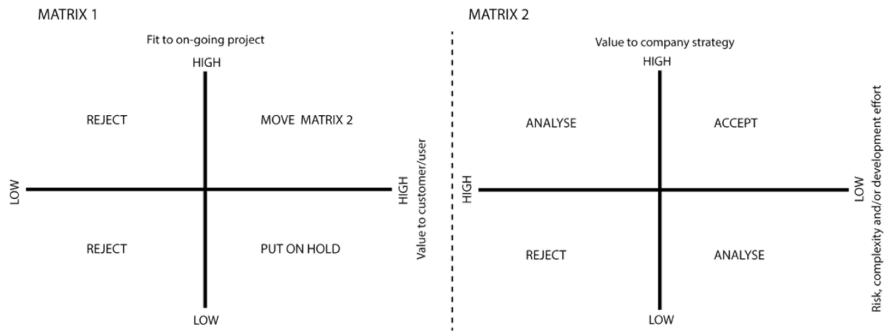
Figure 8: Dimensions used for evaluating ideas.

In addition to the idea evaluations, observations were made regarding the meaning of each idea evaluation category, such as the interpretation of the pre-defined criteria by the participants. First, ideas evaluated as *put on hold* were quickly identified because they often represented radically different (or novel) ideas. One company even jokingly re-named this the 'patent'-category, implying that these ideas were new and radical and thus possessed potential value, but were not suitable for the current project due to the timescale or resources necessary to pursue and explore it further. Second, *accept* category ideas were also rapidly classified; however, unlike the previous category, the *accept* ideas were more often characterised as being existing and easily understandable solutions drawn from similar products. Third, the *analyse* category ideas were more difficult to define, often resulting in evaluators deliberating whether the idea would belong to the *analyse* or *accept* categories, indicating that such ideas had a value although they were not clear enough to make a final decision on acceptance without more information. Fourth, *reject* category ideas stemmed from three different quadrants in the evaluation matrices (refer to Figure 8) and as such did not display any immediately observable characteristics.

Example 4

Example 4 in Table 35 illustrates an idea episode from the protocols of Company A. The idea was evaluated and assigned to the *reject* category.

Row	Speaker	Utterance	Idea	Reasoning type
1	A	if you could minimise the entire pulley	idea	abductive
2	A	or then just have a reel or a caster	idea	abductive
3	A	that you find on the American solutions,	idea	deductive
4	A	but then you just do a pre…	idea	deductive
5	A	use a bit more to prepare	idea	deductive
6	A	so, you drive it to the window,	idea	deductive
7	A	in the right distance mount it	idea	deductive
8	A	and then you just have to lift it 3-4 cm	idea	deductive
9	A	and then you have the adjustment and lift it again	idea	deductive
10	A	so you minimise the entire phase of pulling and lifting	idea	deductive
11	A	so you just do it manually	idea	deductive
12	B	It could also be that you used the pulley to drive the wheel,	idea aspect	abductive
13	B	so you extend it and attach the hook	idea aspect	deductive
14	B	oh wait no, but, well…	idea aspect	
15	B	it is silly as it is now	idea aspect	inductive
16	B	but it could be with the same motor	idea aspect	deductive
17	B	when it is attached to the cart base	idea aspect	deductive

| 18 | B | then there is some sort of gearing to the wheel, | idea aspect | deductive |
| 19 | B | same engine drives and pulls… | idea aspect | deductive |

Table 35: Example 4: Idea episode from protocols, translated into English for reporting.

The idea presented in the example shows how the idea begins as abductive reasoning by proposing to minimise or remove a product component, in this case the pulley (Table 35, rows 1-2). Next, a sequence of deductions occurs, exploring solutions (rows 3-11). Subsequently, a second participant contributes and re-frames the solutions by suggesting an alternative use of the component initially sought to be minimized (row 12). After this, deductive reasoning follows to explore the new framing (rows 13 and 16-19), only interrupted by an instance of inductive reasoning in the form of an utterance of judgement regarding the present solution (row 15).

From the example, two observations stand out as pertaining to the research. First, abductive reasoning conveys novel frames and thus a higher degree of uncertainty in the sense that in itself the abduction does not provide an explanation of a possible solution. In the example, this triggers deductive reasoning to provide a possible solution, thus decreasing the overall proportion of abductive reasoning in the idea when a concrete solution to the frame is proposed. Second, as the idea progresses, the likelihood of other participants' involvement in the generation process increases, hence as the amount of reasoning accumulates, the multiple frames for possible solutions also increase, making it more difficult to ascertain the core of the idea. This is a plausible source of confusion when the idea is later evaluated, leading to ideas with high amounts of reasoning occurrence (effort) being more likely to be either rejected or in need of further analysis (refer to Section 5.3.4).

Picture 3 shows screen dumps from the recordings of the four companies participating in Study 2.
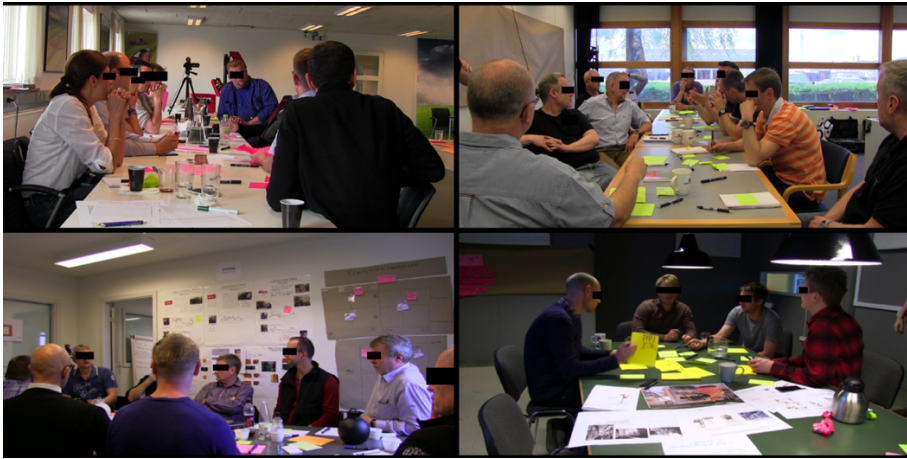
Picture 3: Screen dumps from the recordings of the four companies participating in Study 2.

5.3.4   Testing the effect of reasoning patterns on idea value

As presented earlier, a set of hypotheses predicted the influence of reasoning patterns on the later evaluation of ideas:

HS2b:

The proportion of abductive reasoning is higher for ideas evaluated as too uncertain or radical for an on-going design process, whereas ideas that are accepted for further work have a comparably higher proportion of deductive reasoning.

The *reject* evaluation category was not part of the hypothesis since the category encompasses ideas from both Matrices 1 and 2, but it is still included in the analysis for clarity.

HS2c:

Ideas evaluated as valuable, and thus accepted for further work, contain more reasoning occurrences than those ideas not accepted.

The data were not normally distributed, as determined by a Shapiro-Wilk test. Hence, a non-parametric Kruskal-Wallis test was conducted to determine if there were differences in the proportion of abductive reasoning between idea evaluation categories. Distributions of proportions of

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abductive reasoning were similar for all categories, as evaluated by visual inspection of a boxplot. The proportion of abductive reasoning was found to be significantly different between the idea evaluation categories, $\chi^2(3)$ = 41.976, p < .001. Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. Adjusted p-values are reported. This post hoc analysis revealed statistically significant differences in median proportions of abductive reasoning between the *reject* (11.4%) and *put on hold* categories (22.2%; p = .006), *put on hold* and *accept* categories (0%; p < .001) and *analyse* (11.1%) and *accept* categories (p = .005). Hence, **HS2b** is supported since both the *put on hold* and *analyse* categories had medians that were both significantly different and higher than those of the *accept* category. No other combinations were statistically significant.

Prior to testing **HS2c**, the data needed to be normalised as the mean amount of reasoning for Company A (20.3) was much higher than that of the other companies (ranging from 6.6 to 7.7, refer to Table 31). This approach was adopted to normalise each individual group by mean in the analysis. Despite the mean normalisation of the variable, the data were not normally distributed per a Shapiro-Wilk test. Hence, a Kruskal-Wallis test was conducted to determine if there were differences in the mean normalised amount of reasoning between idea evaluation categories. Distributions of mean normalised amount of reasoning were similar for all categories, as evaluated by visual inspection of a boxplot. The mean normalised amount of reasoning was not statistically significantly different between the idea evaluation categories, $\chi^2(3)$ = 5.200, p = .158. Hence, **HS2c** was not supported.

Table 36 summarises the median values used to test the hypotheses and also reports the corresponding mean values, which are more descriptive than the median values.

Idea evaluation	Reject	Put on hold	Analyse	Accept
Median of mean normalised amount of reasoning	1.01	.79	1.14	.79

	1.17	.96	1.17	.99
Mean amount of reasoning	1.17	.96	1.17	.99
Median proportion of abductive reasoning	11.4%	22.2%	11.1%	0%
Mean proportion of abductive reasoning	12.1%	27.1%	19.4%	9.7%

Table 36: Median and mean values of reasoning pattern characteristics displayed by idea evaluation categories.

From inspecting Table 36, two observations can be made. First, contrary to what was predicted by **HS2c,** the *accept* category had the lowest median amount of reasoning along with the *put on hold* category. Despite not finding support for the hypothesis, a difference is observable in that the *put on hold* and *accept* categories (both .79) are shorter than *reject* (1.01) and *analyse* (1.14), suggesting that classifying the feasible and radical ideas (*accept* and *put on hold* categories) required equally little reasoning effort, while ideas needing further work (*analyse* category) demanded more reasoning.

The second observation is that there are marked differences when observing the proportion of abductive reasoning median and mean values for the *analyse* and *accept* categories, respectively. The *analyse* category possessed a median value (11.1%), that is almost half that of the mean value (19.4%), and the *accept* category produced a median value (0%) that also differed from the mean value (9.7%). Hence, examining the mean values, another two groups emerge: one group containing the *reject* (12.1%) and *accept* (9.7%) categories with relatively smaller mean values than that of the other group consisting of the *put on hold* (27.1%) and *analyse* (19.4%) categories. Since the abductive reasoning proportion is calculated from a relatively low number of occurrences, this is reflected in the median values approaching simple fractional values (e.g., 0%, 11.1% or 22.1% as reported in Table 36). Thus, it is relevant to further investigate the above two groups of idea evaluations despite their being derived from mean values in a non-normal distribution, implying uncertainty about the variation of the results.

Hence, while the hypotheses addressed the first research issue, the two observations described above justified the formulation of a second set of hypotheses. Testing these new hypotheses allowed for a more

comprehensive response to the research issue of understanding how reasoning patterns influence idea value through their evaluation.

5.3.5 Second set of hypotheses

Table 37 presents the new categories. As shown, 2×2 groups are generated, as a product of the results presented in Table 36. That is, the groups are explained by the initial analysis of how the four idea evaluation categories contained either low or high proportions of abductive reasoning and low or high occurrences of reasoning.

	Abductive category	**Effort category**
HIGH	Put on hold	Reject
	Analyse	Analyse
LOW	Reject	Put on hold
	Accept	Accept

Table 37: Idea evaluation category groups hypothesised to be predicable by reasoning patterns.

In relation to the proportion of abductive reasoning, a group with higher mean values consists of *put on hold* and *analyse* categories and a group with lower mean values consists of *reject* and *accept* categories. Therefore, Hypothesis **HS2d** is supported:

An increasing proportion of abductive reasoning is predictive of ideas being evaluated as falling into the put on hold or analyse categories instead of reject or accept categories.

In relation to the mean normalised amount of reasoning (refer to Table 36), the group with the higher median values consisted of the *reject* and *analyse* categories, and the group with low median values consisted of the *put on hold* and *accept* categories. This is in line with Hypothesis **HS2e**:

An increasing effort, in terms of amount of reasoning, is predictive of ideas being evaluated as reject or analyse categories instead of put on hold or accept categories.

5.3.5.1 Results of second set of hypotheses

The division of idea evaluation categories into two sets of dichotomous variables (high/low values) allows for the application of a binomial logistic regression to test the hypotheses. This method provides a different type of result than the Kruskal-Wallis tests applied earlier as it identifies any linear effects between the tested variables. To consider the possible influence of other factors, the tests controlled for company and for the type of constraint (user/customer vs. cost focus, as explained in Section 4.5.2) used in the idea generation. The former was introduced as a categorical variable counting the four companies; the latter as a dichotomous variable specifying either a focus on solutions with no constraints (focus on customer/user needs) or a focus on solutions with ideas being required to stem from existing solutions (based on analyses of competitor products).

Abduction vs. evaluation

To test **HS2d**, a binomial logistic regression was performed to ascertain the effects of the proportion of abductive reasoning in ideas, controlling for company and idea generation condition, on the likelihood that ideas were evaluated as belonging to the *analyse-put on hold* category. In other words, this analysis was done to determine whether increasing proportions of abductive reasoning made it more likely that ideas would be evaluated as belonging to the *put on hold* or *accept* categories.

The logistic regression model was found to be statistically significant, $\chi^2(5) = 42.967$, p < .0005. The model explained 19,7% (Nagelkerke R^2) of the variance in the *analyse-put on hold* category and correctly classified 74.7% of cases. The predictor variable used for testing the hypothesis, proportion of abductive reasoning, was statistically significant (p < .001), showing that a proportion of 100% abductive reasoning had 40.68 times higher odds of belonging to the *analyse-put on hold* category compared to 0% abductive reasoning. Hence, Hypothesis **HS2d** was supported. Both of the two control variables, company and idea generation condition, were statistically significant. Table 38 presents the results of the analysis.

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	B	SE	Wald	df	Sig.	Odds ratio
Proportion of abductive reasoning	3.706	.766	23.426	1	p < .001	40.684
Company	-	-	8.964	3	p = .030	-
Idea generation condition	-.324	.152	4.516	1	p = .034	.723
Constant	-1.517	.194	61.017	1	p < .001	.219

Table 38: Binomial logistic regression predicting the likelihood of idea category based on type of proportion of abductive reasoning, controlling for company and idea generation condition.

The analysis shows that the proportion of abductive reasoning was strongly predictive of whether ideas were considered to belong in either of the two groups. Higher proportions of abductive reasoning led to ideas being evaluated as being in either the *put on hold* or *analyse* categories, while lower proportions of abductive reasoning predicted that ideas would fall into the *reject* or *accept* categories. Hence, the idea categories of *put on hold* and *analyse* entail a higher degree of novelty and uncertainty. To reiterate, such ideas were categorised as being either valuable to customer/user, but not fitting for the current project (*put on hold* category) or deemed useful to the project but either requiring extra clarification or not congruent with the company strategy (*analyse* category). In contrast, for ideas evaluated as *reject* or *accept*, lower degrees of novelty were predicted by the analysis, suggesting that such ideas are easier to assess using a direct 'yes' (*accept* category) or 'no' (*reject* category) evaluation.

Effort vs. evaluation

Addressing Hypothesis **HS2e**, a binomial logistic regression was performed to ascertain the effects of the mean normalized amount of reasoning in ideas, controlling for company and idea generation condition, on the probability that ideas would be sorted into the *reject-analyse* category in order to determine whether more reasoning effort is predictive of ideas being evaluated as belonging to the *reject* or *analyse* categories.

The logistic regression model was found to be statistically significant, $\chi^2(5)$ = 20.505, p = .001. The model explained 9,7% (Nagelkerke R^2) of the variance in the *reject-analyse* category and correctly classified 75.1% of cases. The predictor variable used for testing the hypothesis, the mean normalized amount of reasoning, was statistically significant (p = .041), showing that an increase of one normalised mean led to a 1.455 times higher odds ratio of belonging to the *reject-analyse* category. Hence, **HS2e** was supported. Both of the two control variables, particularly the difference across companies, were statistically significant and explained by the difference between Company A and the others, which is corrected for using the mean normalization of amount of reasoning. Table 39 presents the results of the analysis.

	B	SE	Wald	df	Sig.	Odds ratio
Mean normalised amount of reasoning	.375	.184	4.168	1	p = .041	1.455
Company	-	-	14.014	3	p = .003	-
Idea generation condition	-.628	.296	4.483	1	p = .034	.534
Constant	-1.598	.365	19.117	1	p < .001	.202

Table 39: Binomial logistic regression predicting the likelihood of idea evaluation based on type of mean normalised amount of reasoning, controlling for company and idea generation condition.

The analysis of the mean normalised amount of reasoning utterances, interpreted as the effort directed at ideas, shows that the effort was predictive of whether ideas were evaluated in either of the two groups. A higher amount of effort predicts ideas being evaluated as either *reject* or *analyse*, while a lower amount of effort predicts ideas being evaluated as either *accept* or *put on hold*. Hence, the analysis suggests that *accept* or *put on hold* ideas (i.e., evaluated to be valuable, but not fitting the current project) require less reasoning and are thus quicker to classify, resulting in less dialogue between the participants. In contrast, the *reject* and *analyse* categories require more reasoning, suggesting that their implications are unclear and demand more effort.

5.3.6 Discussion of results: Relationship of reasoning pattern to idea evaluation and value

Next, the results pertaining to the research issue investigating the relationship between reasoning patterns in the process of generating ideas and the later evaluation according to their value to an ongoing design process are discussed. First, the framing effects of reasoning types on idea evaluation are discussed. Next, the results of the hypotheses enable an exploration of the reasoning patterns' ability to predict idea evaluation

categories and are used to provide a characteristic of the idea evaluation categories. Finally, the relationship between reasoning patterns and innovativeness is discussed.

5.3.6.1 *Framing effects of reasoning patterns*

The analysis of reasoning types used to start ideas showed that an important relationship exists between how ideas are framed and its moderately strong influence on how ideas are later evaluated. The results imply that the use of reasoning patterns to understand idea generation activity means that the value of an idea, or how it will be evaluated, can be predicted, and is enacted, by the reasoning used at its inception. Studies of design activity have traditionally focused mainly on analyses of behaviours to infer cognitive mechanisms that are independent from, or precede, the actual design activity (Cross, 2001). However, the research empirically shows that the utterances in design activity have a performative function in themselves and thus guide activity (Dong *et al.*, 2016). This is highlighted in the case of abductive reasoning, as it is more likely to initiate ideas and also has the most pronounced effect on idea evaluation, as established in Section 5.3.2. Thus, the study contributes to the growing focus on the performative aspect of design discourse as something different from cognitive aspects of design activity (Dong, 2007).

Pertaining to the specific results, abductive reasoning leads to more radical ideas and makes it possible to argue that the uncertain and 'open' form of abductive reasoning carries a greater likelihood of more abductive reasoning appearing in the development of the idea, entailing new perspectives and ways of 'seeing' the problem, signifying more radically different ideas (Roozenburg, 1993). At the same time, the definitive form of deductive reasoning constrains the remaining reasoning sequence to be less 'open' to redefine the initial framing. We attribute this to the certain and definitive character of deductive reasoning (Fann, 1970).

Hence, ideas that begin with deductive reasoning risk missing out on alternative solutions and ideas started by abductive reasoning and also may have decreased chances of being accepted due to being unfit for the situation, such as the constraints set by a product development project or the biases held by those evaluating them (Blair & Mumford, 2007). Reviewed

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studies support the influence of either the wording used for design or the way situations are framed and established (Darke, 1979; Dong, 2007; Stumpf & McDonnell, 2002).

5.3.6.2 Reasoning pattern effect on idea value

Hypothesis **HS2b** stated that *put on hold* and *analyse* ideas contained more abductive reasoning than *accept* ideas and was supported, and **HS2d** stated that the proportion of abductive reasoning was predictive of whether ideas were likely to belong to either a *put on hold-analyse* or a *reject-accept* evaluation group. Together, the results of the hypotheses imply that ideas with a high degree of novelty are subject to a deferred judgment, while ideas with little or no novelty are more directly evaluated (i.e., accepted or rejected). This result contributes to the existing literature by providing an empirically based demonstration of how ideas may be subject to risk averseness (Blair & Mumford, 2007) and further shows that such ideas are recognised for their potential value and thus not plainly rejected. This has implications for idea generation activity in the sense that such uncertain ideas should be subject to further clarification as they hold the potential for innovation because of their abductive element, which is central in design (Dorst, 2011; Roozenburg, 1993).

Hypothesis **HS2c** stated that the effort put into ideas generated was higher for *accept* ideas than other ideas, but this was not supported. However **HS2e,** stating that the reasoning effort was predictive of whether ideas were likely to belong to either a *reject-analyse* or a *put on hold-accept* evaluation group, was supported. The latter hypothesis showed that ideas evaluated as *put on hold* or *accept* were predicted by requiring less reasoning effort to generate than the other categories. A possible explanation for this is that greater effort used to generate ideas is indicative of an inability to reach a common understanding between the participants of the process. This is based on the qualitative interpretation from observing the idea evaluation process in the four companies, which found *accept* and *put on hold* ideas to be faster to evaluate in general. The argument implies that ideas such as those in the *reject* and *analyse* categories are more unclear, which manifests as more effort required when such ideas are generated.

5.3.7 Characteristics of idea evaluation categories

The results of the analyses allow for relating reasoning patterns to the value of ideas. To illustrate this further, each idea evaluation category is characterised in relative terms to each other in the following sections.

Put on hold (low fit to ongoing project, high value to user/customer) category ideas had a high degree of novelty (22.2% median abductive reasoning) and required lower amounts of effort (.79 median mean normalised amount of reasoning). Ideas that entail a high degree of novelty and uncertainty give way to low reasoning effort since it quickly becomes clear that the idea is not appropriate for the ongoing project. This indicates that they are radically different from existing solutions, and they may have value in other projects. No existing frame allows its evaluation, so the degree of novelty results in a lack of information about whether the idea is operational (Licuanan *et al.*, 2007).

Analyse (low strategic fit and low risk/complexity, or high strategic fit and high risk/complexity) category ideas had an average degree of novelty (11.1% median abductive reasoning) and required a high amount of effort to clarify (1.14 median mean normalised amount of reasoning). These ideas introduce new and potentially valuable solutions, but require a high effort to clarify. Therefore, such ideas are not rejected outright but rather are deemed to require more work to determine their value to the ongoing project. As with *put on hold* category ideas, Licuanan *et al.* (2007) offers the explanation that *analyse* ideas may lack information and frames for evaluation. Unlike *put on hold* ideas, however, since the degree of novelty is lower, the ideas are not immediately evaluated as not being valuable to the ongoing project. Instead, they are offered a 'second chance' in the form of the desire for more clarification to ascertain their value.

Accept (high strategic fit and low risk/complexity) category ideas had a low degree of novelty (0% median abductive reasoning) and also required lower amounts of effort (.79 median mean normalised amount of reasoning). *Accept* ideas rely on existing solutions to a high degree, and thus entail little or no uncertainty and require little clarification. Therefore, such ideas are most often accepted as valuable, indicating a strong bias towards ideas that are aligned to within-domain solutions and thus encourage incremental

innovation (Ward, 2008), as opposed to the *put on hold* and *analyse* categories, which introduce more novel, and possibly domain independent, solutions.

Reject (either low value to customer/user or high risk/complexity and low strategic fit) category ideas have an average degree of novelty (11.4% median abductive reasoning) and require an average amount of effort (1.01 median mean normalised amount of reasoning). As the *reject* category contains ideas evaluated differently according to the four criteria, it is expectedly more difficult to provide a clear explanation for this categorization.

Figure 9 illustrates the four evaluation categories graphically while adding descriptive keywords to the general characteristics of the idea evaluation categories.

High effort

Reject
- Not valuable to project

Analyse
- Need more analysis to determine value

Low proportion of abductive reasoning

High proportion of abductive reasoning

Accept
- Useful, but not novel
- Immediately valuable to project
- Incremental innovation

Radical
- Novel, but not useful
- Not valuable to current project
- Radical innovation

Low effort
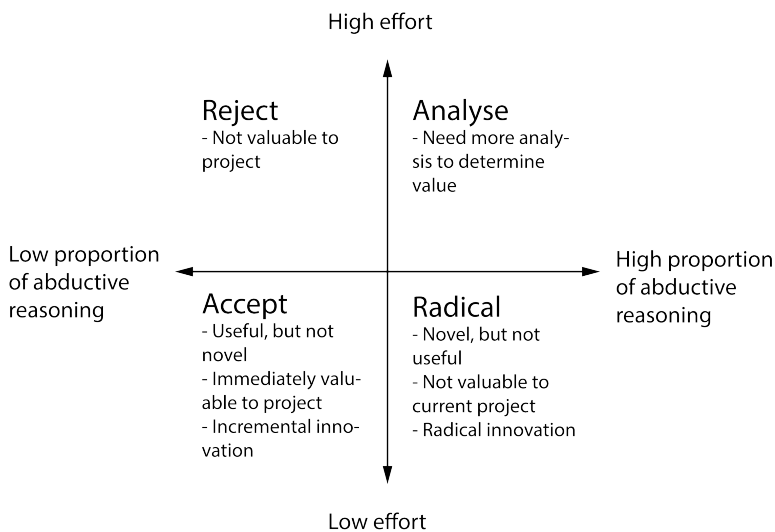
Figure 9: Illustration of the four idea evaluation categories and their relation to reasoning patterns.

The insight into idea evaluation metrics from the study contribute to an understanding of how such metrics and categories are traceable to their inception. This is made possible through analysing the reasoning patterns of the dialogue when ideas are first presented and debated between participants on a design team. Additionally, this insight can be useful in

practice as a means for designers to reflect on their decisions when evaluating ideas. For research, the insight opens up new perspectives on the evaluation of ideas when those evaluating have themselves been part of the idea generation. Hence, the evaluation is about more than a sticky note; it is a representation of something that carries the dialogue and perspectives of the team when evaluating ideas according to their value.

5.3.8 Reasoning patterns to understand and influence idea generation innovativeness

The characterisation of generated ideas afforded by the analysis of reasoning pattern provides a means to understand how reasoning patterns influence the evaluated idea value. In particular, judging from the degree of novelty in ideas and the relation to idea evaluation, a pattern emerges in regard to which proportions of abductive reasoning are desirable to a creative process. The analysis of the data found that accepted ideas had a median proportion of reasoning of 0%, predicting that solutions resulting from the development processes will be incremental because the framing of ideas generally proceeds in deductive patterns indicating either a presentation of existing solutions or the analogical transfer of ideas from other areas. While the use of analogy has been shown to provide novel solutions (Christensen & Schunn, 2007), it is expected to be seen in only a few cases. Given the observation that *analyse* ideas (with 11.1% median abductive reasoning) qualify as ideas that are likely to be valuable to the process, the proportion of abductive reasoning used for idea generation is a variable related to the level of innovativeness desired in an idea generation process. As such, for the companies in the present study, a relatively low degree of novelty was desired due to constraints such as time and resources, while other, more innovative projects may require higher degrees of novelty. One such example is wishing to generate ideas similar to those evaluated as *put on hold* in the present study.

Hence, the results of the analysis of reasoning patterns and their influence on idea evaluation contribute empirical evidence for a correlation between abductive reasoning and the innovativeness of ideas by demonstrating how reasoning behaviour during idea generation activity in an industrial context influences the evaluation of whether, and how, ideas add value to the continued innovation process, which is central to innovation (Björk *et al.*,

2010; Cross, 2006). The results also show, as demonstrated by Example 4 in Table 35, that the characteristics of the reasoning types are distinguishable from learning to understand the dialogue. Hence, with training it is possible to aggregate this understanding of the effects of certain reasoning patterns to monitor idea generation as it happens. The implication of the results is twofold. First, the results show that reasoning types and occurrence are important to the later value of generated ideas. As such, the study contributes to existing knowledge by providing evidence of how specific behaviours in idea generation affects the value of outcome ideas, in this case reasoning types, which qualifies the range of studies investigating the balance between framing and solution-oriented activity in idea generation (Dorst & Cross, 2001; Valkenburg & Dorst, 1998). Second, the degree of novelty is shown through the level of abductive reasoning in ideas, and the effort used to produce ideas indicates the extent to which ideas are clear and can add value to the process.

To summarise Study 2 – SMART, it was found that:

- The reasoning patterns occurring during idea generation enact the design activity in such a way that the idea evaluation categories can be predicted from these patterns.
- There is a correlation between the proportion of abductive reasoning present when an idea is generated and how innovative, or different from existing solutions, the idea is evaluated to be. This implies that the degree of abductive contributions when generating ideas is strongly influential on ideas.
- The use of simple combinations of reasoning patterns can predict how ideas are later evaluated to have value to the ongoing product development process.

6 DISCUSSION

This chapter draws together the findings of the previous chapters into a final discussion of the research.

First, the initially proposed research issues are revisited and their implications discussed in relation to the chosen research methodology, study designs and results. From this, the main contributions of the research are presented. Second, the limitations of the research methodology, the studies and the results are described. Third, avenues for further research and new questions raised by the thesis research are presented.

6.1 RESEARCH ISSUES

This section discusses the initial research questions and the contributions and implications of the research to education, research and practice. This is based on the separate discussions following each analysis in the previous chapter.

6.1.1 Research issue 1: Analysing micro-level reasoning in design

First and foremost, the empirical analysis of reasoning implies studying design as a process of argumentation (Rittel, 1987). The research has shown that the argumentative aspects indicate that reasoning is not merely a logical, monotonous phenomenon but one that is influenced by several factors.

The empirical reasoning patterns identified, as shown through the various examples throughout the thesis, delves into processes of micro-inferences in which multiple reasoning types interact. In these chains of inference, the reasoning occurrences are interdependent, and the analysis method presented here allows a fine-grained analysis – both qualitatively and quantitatively, as discussed later – of how ideas develop.

One characteristic of such chains of micro-inference is that the reasoning is non-monotonous, implying that the reasoning used does not exclusively refer to logically inferred premises or 'facts', but rather draws upon hunches, beliefs or immediate preferences. As with established and agreed-upon

knowledge, the various grounds for reasoning are based on mental models that prescribe how individuals act in a situation. Hence, the verbal reasoning indicates different mental models held or 'run' by those involved in design activity. One case of mental models influencing reasoning is shown in Example 2 (Table 24), where a mental model is applied through analogical transfer of an idea from elsewhere. A different case showing the influence of mental models is seen in Example 4 (Table 35), where the mental model is explicated through an abductive framing, proposing a change to an existing design after which the imagined consequence of the change is simulated (Ball & Christensen, 2009).

The framing effect illustrates a different characteristic of verbal reasoning. As shown by the analyses, the type of reasoning used when generating ideas is important to how other participants in a group idea generation session perceive and respond – both in terms of the ongoing creative process and in relation to the later-evaluated value of ideas. This suggests that the type of reasoning used when generating ideas enacts certain models through language. In other words, the reasoning is performative. Where the previously mentioned mental models signify the underlying knowledge used for reasoning, the performative aspect emphasises how the reasoning used to argue for ideas is also decisive for design activity. There is empirical evidence for this through **HS2a,** showing that the evaluation of idea value was strongly dependent on the type of reasoning that initiated the ideas.

The above characteristics of verbal reasoning demonstrate a design activity as being informal and complex, suggesting that design problems are difficult and disorderly (Buchanan, 1992). For the analysis of verbal reasoning, this implies that the results must accept multiple possible courses of explanation, but should not result in refraining from further analysing the topic.

Validity of verbal reasoning

Given the above discussion of how verbal reasoning rests on multiple, interconnected factors, the validity of using verbal reasoning to understand design activity is now discussed.

To ensure external validity, the development of the coding scheme had two aims. The first was to draw on tested and recognised models of design

activity to define how reasoning appears in empirical data when developing the coding scheme, and the second to compare the patterns of reasoning in design activity gained from coding to the patterns proposed theoretically to determine any similarities. This would be a sign of validity as opposed to a case with no concordance between theoretical models and empirical results. A result of this process was the choice to discard the initial coding scheme based on propositional logic (refer to Section 0) and to apply a different coding scheme more aligned with the data. The results of **HS1a** and **HS1b** showing the presence of abductive-deductive patterns is one such basis on which validity can be claimed.

As discussed in the previous paragraphs, there are differences from the formal reasoning types defined by Peirce (1980) and also from those proposed by other researchers in design (Dong *et al.*, 2016; Dorst, 2011; Roozenburg, 1993). Nevertheless, as also discussed earlier, the present coding scheme is not meant to refute earlier work, but instead seeks to shed more light on design activity by providing a different perspective on reasoning in design: a perspective dependent on reasoning made verbally explicit in order to ascertain reasoning patterns. Such reasoning appears to be representative of the actual reasoning taking place between groups of people in design activity (Rittel, 1987) and allows for answering different questions about design activity, discussed earlier and in the next sections.

Reliability of method

An inter-coder reliability check was chosen as the primary method to determine reliability of the coding scheme. As reported earlier, the results were acceptable, through with some room for improvement. A different indicator for reliability is that the protocols showed a strong robustness within and across the two studies, as shown in Section 5.2.1. This concerned:

- Similarities in the proportional distributions of reasoning types in idea episodes.
- The importance of abductive-deductive reasoning patterns in both study protocols.

6.1.1.1   *Outcome of method*

The coding scheme was successful in allowing an empirical analysis of reasoning at a level of analysis not before shown in existing literature. Such an analysis can identify patterns of reasoning at a high resolution and empirically show patterns of reasoning similar to those proposed in previous literature, as reviewed later.

While showing robustness in the patterns of reasoning across studies, the coding scheme also found significant correlations and effects on design activity and outcomes through identifying specific variations in reasoning patterns.

6.1.2   Research issue 2: Determining the patterns of reasoning taking place during idea generation

The research has identified four reasoning patterns that significantly influence design activity, as well as a 'non-pattern' pertaining to inductive reasoning.

Perhaps the strongest recurring pattern in the research is the presence of abductive-deductive patterns. These patterns are similar to analysis-synthesis (Roozenburg & Cross, 1991) behaviour and generally conform to the core aspects of design activity, whether described as production and deduction (March, 1976), framing and moving (Schön, 1991), conceptual and knowledge-based spaces (Hatchuel & Weil, 2008), or in terms of how design problem and solutions co-evolve (Dorst & Cross, 2001; Wiltschnig, Ball & Christensen, 2013) and go through divergent-convergent phases. Hence, the evidence from the present research confirms the presence of such behaviours at a micro-level and in a context of idea generation.

The primary contribution of the thesis, however, is not in testing and verifying existing models of design activity, but in demonstrating what such reasoning patterns mean for the process and value of design. Below, the four significant reasoning patterns are presented along with their found influence(s) on design activity. Finally, the relationship of the results with other studies of reasoning in design are discussed.

Pattern 1: Abductive-deductive reasoning patterns

- **HS1a** and **HS1b** combined showed how abductive reasoning is concentrated in the beginning of ideas, after which deductive reasoning becomes prominent, showing how the two types are prominent in idea generation activity.

Two hypotheses tested the effect of abductive-deductive reasoning patterns on design activity.

- **HS1d** showed a significant ability, albeit not a strong one, to predict breadth moves even when controlling for the use of reasoning to start ideas (HS1c).
- **HS1f** exhibited a significant ability to predict the extent to which an idea theme would become more prevalent when an abductive-deductive pattern arose during idea generation.

Pattern 2: Proportion of reasoning in idea episodes

- **HS2b** revealed a relationship between the proportion of abductive reasoning increasing the chance of an idea being evaluated as too radical for ongoing (incremental) product development projects, and deductive reasoning increasing the chance that ideas were evaluated as acceptable. This relationship was explored further in HS2d and HS2e.
- **HS2d** showed a strong relationship between the increasing proportion of abductive reasoning and the chance that ideas would be evaluated as radical or needing further analysis compared to lower proportions increasing the chance of ideas being rejected or accepted outright.

Pattern 3: Amount of reasoning in idea episodes

- **HS1g** showed a significant relationship between a higher number of depth moves following the initial mention of an idea theme leading to the prevalence of that theme later on.
- **HS2c** did not show a significant relationship between the amount of reasoning taking place when ideas were generated and the acceptance of ideas. However, **HS2e** showed a linear

relationship where the higher amount of reasoning led to ideas being evaluated as *reject* or *analyse* and vice versa for ideas evaluated as radical or accepted.

Pattern 4: Reasoning type used to initiate design moves

- **HS1c** indicated a strong significant relationship between the type of reasoning used to start a design move and the classification of that design move as either breadth or depth. Abductive reasoning correlated with breadth moves, and deductive reasoning with depth moves.
- **HS1e** did not show a significant relationship between the reasoning used to start idea themes and the prevalence of the theme in later design moves.
- **HS2a** showed that the evaluation of ideas was strongly dependent on the reasoning type (abductive or deductive) used to start ideas, and that abductively started ideas were more likely to be radical or in need of more analysis while deductively started ideas were more likely to be accepted.

'Non-pattern': The absence of inductive reasoning

- The role of inductive reasoning in design activity, originally proposed by March (1976) but subject to some debate in more recent literature (Koskela *et al.*, 2018; Roozenburg, 1993), was investigated as part of the research. As the results of the protocols showed, there were low proportions of inductive reasoning present. While even low proportions of reasoning may be important, the presence of inductive reasoning did not have significant effects on the ideas generated, whether analysed quantitatively or qualitatively. A partial explanation for this is the evaluative role that deductive reasoning takes as part of mental simulations (Ball & Christensen, 2009) when evaluating initial frames through exploration of appropriate solutions (see e.g., Example 4, Table 35).

6.1.2.1   Relationship to other studies of reasoning in design

As previously presented in Section 0, the applied coding scheme for reasoning differs from previous studies according to segmentation, data collection method (concurrent verbalisation) and definitions used for coding. Hence, when evaluating the relationship between the results of present research to similar studies, it is difficult to make a comparison. Other studies have been concerned with determining a single overarching type of reasoning in their units of analysis (Dong *et al.*, 2015; Galle, 1996b; Lloyd & Scott, 1994), and thus did not allow for quantitative comparisons. However, judging from qualitative analyses, the observations are similar to the extent that the datasets are comparable. For example, Galle reports verbatim protocols from replication protocol data (Galle, 1996a), and Dong *et al.* (2015) report data from concurrent verbalisation, although from sessions concerned with design idea evaluation. Nevertheless, the data, specifically from Dong *et al.* (2015) and Lloyd and Scott (1994), using think-aloud protocol analysis shows similarities in the methods' affordances in interpreting micro-level design activity.

More similarities exist in comparisons to models of design activity. As discussed above in relation to the abductive-deductive patterns, there is a general alignment between models of design and the empirical evidence from present research. There are, however, also differences between what is proposed in the models and what is clear through the evidence of the research.

Second, the specific stages prescribed by the models of design not pertaining to abductive-deductive patterns were not directly investigated in the research. While the qualitative analyses of the data showed various strategies for generating ideas, such as analogical transfer, and thus different specific reasoning patterns, it is not possible to further test the models. Hence, while the role of deductive reasoning could have an evaluative component (refer to Section 5.2.4) that might be similar to the reflective step proposed by Schön (1991) or even the inductive step proposed by March (1976), the evidence does not allow for making general contributions in this regard.

Combining the results of all hypotheses, the effect of reasoning patterns on design activity are discussed in relation to the remaining research issues.

6.1.3 Research issue 3: Correlating reasoning patterns to creative behaviour in problem-solving activity in design

With regards to the correlation between reasoning patterns and problem-solving behaviour, the research has two primary implications.

The first implication is the long-term effect of abductive-deductive patterns on the creative behaviour in design activity, as shown by **HS1f**. Further, the same reasoning patterns have a more limited short-term effect on design activity, as indicated by **HS1d**. Hence, the evidence suggests that the abductive-deductive patterns are indicative of design activity that is influential on design activity across longer timespans in a context of idea generation. Such influence is suggestive of creative quality because of the cumulative effect of the initial themes generated by abductive-deductive patterns (Goldschmidt & Weil, 1998; Gruber, 1980).

The second implication pertains to the type of reasoning used to start design moves that has a strong short-term effect as shown by hypothesis **HS1c**, but drops off over the longer term, seen in the non-significant result of **HS1e**. Adding to the implication is that **HS2a** showed that reasoning type at idea initiation is strongly determinant of how ideas are later evaluated. A plausible way to interpret this short-term effect is as empirical evidence of framing (Schön, 1991) and primary generators (Darke, 1979). That is, since the first type of reasoning is shown to be determinant of how design moves explore a design space (i.e., abductive reasoning determining breath moves and deductive reasoning determining depth moves), the evidence seems to support the notion that design activity tends to follow an initial generator on which an idea is generated. This is also true for the result that reasoning type determines idea evaluation (**HS2a**) in that abductive reasoning is determinant of either radical ideas or ideas requiring more analysis, and deductive reasoning is determinant of accepted ideas.

6.1.4   Research issue 4: Using reasoning patterns to predict the value ideas generated

From the analysis of Study 2 – SMART, the hypotheses presented three primary implications. The first is also touched upon in the above and regards **HS2a** and the initial reasoning type determining later idea evaluation.

The second implication pertains to the use of simple reasoning characteristics – abductive proportions and the amount of reasoning present (effort) – that could predict idea evaluation categories and hence the ideas' value to ongoing development projects in engineering design practice. Namely, the proportion of abductive reasoning was found to be influential on the level of innovativeness of ideas.

The third implication concerns biases in idea generation. As discussed in Section 5.3.6, biases exist against ideas not immediately showing a likeness to similar solutions or ideas having a focus on concrete effects. Such ideas are less likely to be positively evaluated (Lıcuanan *et al.*, 2007), just as ideas perceived to be risky also suffer from negative bias (Blair & Mumford, 2007). While such biases are oftentimes natural and a result of people's accumulated experience and expertise in a field, the data empirically showed how such ideas are often dominated by abductive reasoning. Hence, high proportions of abductive reasoning seem to result in ideas being less concrete or 'thought through' due to the corresponding lower proportion of deductive reasoning.

Together, the results of the research, here summarised according to the research issues, demonstrated that reasoning patterns are a viable means by which to describe design activity. Understanding a small number of relatively simple reasoning patterns can aid in understanding how creative behaviours in design activity are indicative of creative quality and the ways that generated ideas add value to a design process.

Hence, while this research shows robust patterns of reasoning across ideas, it also allows for making predictions about design activity from understanding variations in certain types of reasoning patterns, as described above.

6.2 CONTRIBUTIONS

Below, the contributions of the research are presented and divided into research, practice and education.

6.2.1 Contributions to design research

To design research, the thesis contributes primarily with evidence for micro-level reasoning patterns and how verbal design activity affects the ideas being produced. This is substantial in that it provides evidence for patterns of reasoning that are central to idea generation and for the development of new avenues for conducting research in design and a foundation for developing tool and guidelines for design practitioners.

6.2.1.1 Methodological contributions

The research presents a method for analysing patterns of micro-level reasoning in design activity. This method is new compared to existing methods and approaches to describing reasoning in design and allows for analysis of reasoning from concurrent verbalisation between people engaged in design activity.

The method was developed and tested using different studies of groups engaged in idea generation, both for fictional innovation design tasks and for real-life industry development projects. It provides a means by which to identify reasoning patterns and has allowed the identification of four central reasoning patterns that significantly influence design activity.

6.2.1.2 Theoretical contributions

The thesis contributes to research in creativity and engineering design in different ways.

First, the research provides a novel conceptualisation of reasoning from an empirical perspective. This verbal reasoning allows the analysis of micro-level inferences in design activity, a level of detail not previously explored in the literature.

Second, evidence for micro-level reasoning is presented and shown to be disorderly at the individual idea level (Rittel, 1987), but following distinguishable patterns that are very robust across different analyses and

datasets. These patterns of abductive-deductive reasoning are consonant with several models of design theory.

Third, the study of verbal reasoning implies that many factors influence design activity. That is, reasoning is both reliant on mental models held by individuals (Badke-Schaub *et al.*, 2007; Johnson-Laird, 2010) and at the same time enacts design through language, resulting in a performative aspect (Dong, 2007). This is demonstrated through different reasoning patterns and has been shown to impact both creative behaviour and the value of generated ideas. The research also identified how different reasoning patterns impact design activity differently. Some patterns have immediate effects by framing the dialogue, while other reasoning patterns have longer-term effects on the reasoning.

Fourth, the research contributes to a novel means of characterising idea value through the use of two simple reasoning patterns. The research furthers this contribution by relating reasoning patterns to the biases they introduce, which in turn can be used to develop techniques or strategies to promote different kinds of ideas generated as suits the specific process.

Fifth, the research has the potential to be used to inform other research disciplines that utilise creative problem-solving.

6.2.2   Contributions to design practice

To design practice, the research contributes with a new perspective on how to understand the dialogue taking place when ideas are proposed and presented in teams. This perspective is new in that it provides evidence for the effects of how teams talk to each other and how this affects the later value of ideas. In practical terms, this entails that facilitators and other design professionals must be aware of the way communication and dialogue takes place and provides with insights for specific dialogue behaviours and patterns to be aware of. The research also provides ideas for how to handle and influence the design activity in idea generation through understanding the dialogue and verbal reasoning taking place. More specific insights gleaned from the research are presented below.

The research shows how the form of verbal utterances (i.e., the reasoning) is important to design activity. This is relevant to practitioners because it can

be used for reflection on how certain problem-solving behaviour affects their work. Through the four reasoning patterns identified by the research, it may become possible for trained facilitators and designers to be aware of how the dialogue in design activity develops (in idea generation activity specifically) and to act. For example, the recognition of increasing levels of abductive reasoning (through uncertain statements and new perspectives on a design task) might indicate that a design team is lacking the knowledge or capacity to explore and generate actual solutions. Conversely, the recognition of high levels of deductive reasoning while lacking abductive reasoning might indicate a team is deficient in the ability to reframe and perceive a design problem from new perspectives.

Another contribution to design practice is observations about how reasoning patterns influence the later evaluation of idea value. For example, the correlation between reasoning types used to start ideas is important to note when further developing and evaluating ideas. That is, being aware of the possible framing effects could help prevent fixation (Linsey *et al.*, 2010) on certain ideas and provide a more critical reflection on the premises on which ideas are based and what kind of knowledge such premises draw from – be it natural laws, desires, beliefs, or existing solutions.

Hence, the research provides practical results for observing variations in design dialogue. In extension, the research provides a basis of operationalizable patterns in design activity that can be used to develop tools or methods for improving design activity. Such tools would potentially be able to automatically analyse and diagnose design activity and propose interventions. This possibility is discussed further in Section 6.4

6.2.3 Contributions to design education

To design education, the research is still at an early stage to provide applicable teaching methods or material. The insights from the research are as such still in a foundational stage and will require further work. Below, some actionable insights and ideas for application are suggested.

The results of the research primarily concern the demonstration that reasoning in design between individuals can be perceived as a process of argumentation. This implies that design is not monotonous, and that experience, knowledge and intentions are equally influential factors when

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framing and exploring new ideas to problems. Further, the research provides a set of relatively simple reasoning patterns that could be taught to design students to both help reflect on the impacts of different approaches to solving problems and to be aware of the arguments used for generating new ideas. Hence, the use of retrospective analyses of idea generation activity could aid students and design professionals to identify weak, or even faulty, premises used for reasoning and generating ideas. Such analyses would be similar to the method of arguments analysis used in linguistics or rhetoric (e.g., Kock, 2006; Toulmin, 2003; Voss, 2006).

Additionally, the above contributions to theory and practice are relevant in the training of future engineers, designers or other disciplines that apply creative problem solving.

6.3   LIMITATIONS

This section presents the limitations of the research in terms of the chosen methodological approach and the results of the analyses.

6.3.1   Limitations of methodology
Coding scheme

As discussed previously, and as demonstrated by the examples throughout, the reasoning occurrences found using the coding scheme are not the same as those proposed in conceptual studies (Koskela *et al.*, 2018; Roozenburg, 1993) or as the empirical results described using different units of analyses (Dong *et al.*, 2015) or methods for identifying reasoning (Galle, 1996b; Lloyd & Scott, 1994). Rather, the coding scheme identifies reasoning from concurrent verbalisations. The benefits of this approach have been discussed previously, while the limitations are reviewed here.

First and foremost, the coding scheme identified the reasoning as entering into chains of micro-inference, which is appropriate when analysing design reasoning as a process of argumentation. Consequently, the coding scheme does not allow for capturing and interpreting the overall purposes of reasoning inferences as done in studies of design activity using larger segments as units of analysis (e.g., Atman & Bursic, 1998; Dong *et al.*, 2015; Galle, 1996).

Second, because the coding scheme relates to verbal reasoning, it is naturally limited to the study of design activity in which groups of people share dialogue.

Third, because the coding scheme is the first of its kind to identify reasoning from design as a process of argumentation, the formulation of the codes relied on definitions of reasoning stemming from formal logic. While this permitted the analysis of reasoning and comparison to existing models of design reasoning and activity, the limitation arises when using definitions that are not immediately suitable for capturing the argumentative aspects of verbal reasoning. Despite the coding scheme developing and adapting as part of the research and testing on the data, as described in Section 4.4.1, further effort in refining the code definitions and coding process is likely to improve the analysis method in general.

Fourth, the present analysis method, using word phrases as units of analysis, is very time-consuming as it requires both recording of design activity, transcription of protocols and later coding of many segments, limiting the applicability of the coding scheme. Hence, a further development of the coding scheme would benefit from automations of one of more of the above steps, such as using voice recognition to transcribe and indicator words to automate coding.

Verbal protocol analysis

From a methodological standpoint, the applied verbal analysis adapts tenets from both ethnography (Ball & Ormerod, 2000) and protocol analysis (Ericsson & Simon, 1993). However, in doing so, there are some limitations. First, the applied form of ethnography implies working from *a priori* defined models and definitions in relation to reasoning, risking that the analysis may contain a confirmation bias towards the existing types of reasoning. To mitigate this risk, the data-driven approach was applied to ensure a flexible development of the coding scheme to make sense from the perspective of the data.

Second, the workload required to collect and analyse data using the method is considerable, directly influencing the ability to include more participants

in the studies or to study other instances of design activity that might have improved the results of the analyses.

A final observation as to the use of verbal data is to recognise the complex structure of factors influencing reasoning when perceived as a process of argumentation. As discussed previously, the underlying premises for verbal reasoning (i.e., the utterances) are based on beliefs, facts, knowledge, and attitudes. Hence, the captured reasoning can vary in many ways, and likely does so, across the participants and groups of the studies. This exposes both the great strength and weakness of the research in the thesis – that on the one hand the coding scheme embraces and attempts to explain the factors influencing verbal reasoning, but on the other hand it risks losing explanatory power to the same factors. Nevertheless, the applied method takes these factors into account and proposes a data-driven approach to depict instances of how design occurred and what could be learnt from it.

Differences in reasoning styles

A different possible limitation relates to the different ways in which people 'reason'. That is, reasoning might be contingent on personal styles, cultural norms, or other factors. Concretely, research in design has focused on cognitive styles (Durling, Cross, & Johnson, 1996), and a multitude of personality classification systems exist. The difference shown by such methods might influence the results of the present study.

From a cultural perspective, the styles of reasoning might also differ. For example, drawing on the works of Hofstede (Hofstede, 1984) and his proposed cultural dimensions for distance to power, conflict handling, and so on, might shed light on expected differences in how reasoning in different cultures occurs. The present research used only Danish-speaking participants, which undoubtedly influenced the results. Future research could address reasoning from personal styles or cultural perspectives and might also contribute to the study of groups from different cultural backgrounds, like teams in international organisations.

6.3.2   Limitations of results

The limitations of the results are now discussed.

Participants

A limitation to both the studies is the relatively low number of participants. However, as the segmentation of the protocols provides thousands of segments for each study, they become unmanageable if using an increased number of participants. A possible remedy is to code for reasoning in larger segments, which has already been done elsewhere (see Galle, 1996b; Lloyd & Scott, 1994), or to automate the coding process, as suggested above and further explained later.

However, the data does provide the basis for the quantitative test applied as well as for hundreds of idea episodes on which to conduct the qualitative analysis. Furthermore, because the collected data came from real-world industrial projects and experienced participants, they provide insights into design activity not otherwise possible through controlled experiments where larger samples of students can be recruited (Christensen & Ball, 2014).

The limited participation of facilitators in the idea generation could have potentially affected the results. To account for this, analyses of the data excluding idea episodes in which facilitators contributed to reasoning were conducted, showing no significant differences and the same directionality in the results.

The use of different methods or primes for generating ideas

As described for both studies, the participants were asked to generate ideas using different creative methods for Study 1 and using different criteria (based on background analyses of user/customer insights, competitor products and product cost analyses) for study 2. While these methods arguably influenced the reasoning and creative behaviour of the observed idea generation activity, these were considered when performing statistical analyses on the study data to control for any effects on reasoning patterns and idea value. For Study 1, the group variable was not statistically significant. For Study 2, the companies were a statistically significant variable, which also required the normalisation of the data before testing the hypotheses. Despite the companies being significantly different, the use of

the variable as control ensured that the hypotheses results were still valid to answer the research questions.

For Study 2, the number of rounds of idea generation session ranged from 3 to 5. As explained, they all had the same three conditions for generating ideas: open, user/customer and cost reduction. However, some companies had more rounds than others. This was a consequence of using real-life industrial participants and projects for data collection. To outweigh this potential downside to the comparability of the companies' data, the condition for generating ideas was controlled for in the statistical analyses and proved significant, but only marginally so.

Idea generation as the only analysed phase of the design process

The study was limited to analysing reasoning patterns at a stage of idea generation, which is only one phase of the design process, albeit a critical one (Cross, 2001). As the results also indicate, the idea generation phase contains little inductive reasoning, thus limiting the analysis in Study 1 to concluding any significant patterns for inductive reasoning. Hence, to make the results of the present research more representative of design activity in general, analyses of reasoning patterns at other stages of a design process are appropriate to further test the coding scheme applicability. Such phases could include detail product design, concept evaluation, or usability testing of concepts.

Idea quality and evaluation

The design of Study 1 limits external outcome measures to whether certain patterns or characteristics of verbal reasoning led to greater value in idea generation activity. This is because the study only concerns making inferences to literature that relies on making qualitative observations about quality. Future studies should analyse reasoning patterns to identify reliable outcome measures for idea quality.

In contrast, Study 2 did allow the correlation of reasoning patterns to an external measure because the ideas were evaluated according to their value to the continuing product development process (Cooper, 1990; Cooper & Edgett, 2010). The method used for evaluating ideas was adapted to the specific product development process of participating companies, lacking

the generalisability of techniques introduced earlier, such as psychometric evaluations.

Furthermore, as the review of literature within idea generation showed, there are biases concerned with the evaluation of ideas. Biases such as those against ideas not immediately showing a likeness to similar solutions or a focus on concrete effects mean these ideas are less likely to be positively evaluated (Licuanan *et al.*, 2007), just as ideas perceived as risky also suffer from negative bias (Blair & Mumford, 2007). This result is in concert with the observation that higher proportions of abductive reasoning in the generation of ideas results in ideas being put on hold – that is, deemed unsuitable for immediately contributing to projects. While the reasoning patterns enabled the identification of such biases empirically, the study design did not allow for avoiding the biases.

Statistical analyses

The qualitative coding scheme applied and the later quantitative analysis of results created other limitations to the research. For example, the inherent uncertainty of qualitative coding resulted in the statistical analyses providing simplified results in comparison to the basis. This is a natural trade-off between qualitative and quantitative methods, but because the basis of the quantitative analysis is qualitative interpretations, there is a risk that the results may lack representativeness. Mitigating this risk was the use of inter-coder reliability checks and the use of qualitative observations to interpret and confirm the data.

In terms of the conclusions made based on the statistical analyses, some caution must be taken in regards to both p-values and effect scores. Pertaining to the p-values, most results will always be significant given a high enough n. However, by combining the significance tests with descriptive data, it is possible to derive meaning from the data. Pertaining to the effect scores, some of the applied statistical tests provided effect scores to indicate the strength of results. Whenever such scores were available, they were reported throughout and used in the interpretation and discussion of the results.

6.4 FURTHER RESEARCH

Refining coding scheme

As discussed above, there are several ways to improve the coding scheme. One method is to further refine the coding definitions to better suit the argumentative process it is designed to capture. The present coding scheme applies definitions of reasoning based on formal logic. However, from the studies conducted as part of the research, possible avenues for changing these definitions exist. For example, the formulation of code definitions as a data-driven approach, based on the existing coded protocols, could provide a more accurate means of capturing the argumentative aspects of reasoning. However, not adhering to the more fundamental definitions of reasoning might entirely shift the focus of the research to not explicitly concern reasoning, but rather to operational aspects of dialogue between groups of designers. As long as such aspects are operational and useful for describing and understanding design activity, the initial focus on reasoning does not need to persist.

AI tools to support design practice

A second way to improve the coding scheme is by automating the process. This could be done both in terms of using automatics transcription (a field in rapid technological development) or using such technology to entirely skip the transcription and apply the coding scheme automatically. The latter would then require the coding process to be automated, but this could potentially be possible given the existing use of indicator words in combination with algorithms that analyse the semantics and contexts of dialogue – another field in technological development.

Such automation would finally allow the coding scheme to be turned into a recommender system for diagnosing and amending design activity concurrently to an idea generation session. The findings of the current study provide a basis from which a design AI could propose methods or tools to increase productivity or quality of outcomes. Here, the identified patterns of reasoning critical to design activity can already be used towards such solutions. For example, a system could be used to avoid fixation by ensuring a proper balance between reasoning types to open up new frames for understanding a design task (Linsey *et al.*, 2010). It could be employed to

indicate the lack of knowledge or uncertainty in design activity by recognising an overrepresentation of deductive reasoning used, if a lack of knowledge exists leading to an overly dominant use of simulations, or an overrepresentation of abductive reasoning indicative of uncertainty leading to a lack of ability in a design team to propose concrete ideas and concepts to a design task (Ahmed, Wallace, & Blessing, 2003). The possibilities are many.

Training design facilitators

Using the found reasoning patterns, techniques can be developed and training undertaken to build new competences for managers, consultants and other facilitators of design activity. For example, through an awareness of the factors influencing the reasoning (i.e., facts, beliefs, desires), techniques for critically reflecting and analysing idea generation in retrospect can be developed. From linguistics and rhetoric, existing work could provide the basis of techniques (Kock, 2006; Toulmin, 2003), such as the use of argument analysis and understanding how background knowledge warrants conclusions in the context of design activity (Buchanan, 1985; Rittel, 1987).

Innovativeness and risk management in idea generation and evaluation

In extension of the above, future research could investigate the relationship between novelty tolerance when evaluating ideas and the desired aims of development projects. One example of this is investigating whether there exists too strong a bias against novelty in the team evaluating ideas compared to the desired type of outcome, such as in terms of level of innovativeness. Exploring this relationship is relevant as it can provide both an understanding of innovation processes and act as a foundation for the development of strategic methods. Such methods could clarify and control the degree of novelty to suit a development project or organisation most effectively in terms of generating valuable ideas that balance novel ideas and perspectives with concrete and detailed solutions (Atman *et al.*, 2005). The use of the determined reasoning patterns could provide measures for analysing and understanding such biases and provide foundations for methods to control and steer the idea generation process.

Exploring other phases of the design process

As argued earlier, the empirical data analysed in the present study focused on idea generation activity, and little inductive reasoning and evaluation activity was observed. Hence, future research should emphasise analysing reasoning patterns in similar ways during other stages of design activity, including concept development or detail design to ascertain reasoning patterns present in such phases. Such additional research would naturally be limited to phases of design in which dialogue between group of people organically occur.

Discovering the influence of attitudes, desires, and factual knowledge in design reasoning

The present research does not allow for a detailed analysis of how various factors in design activity influence reasoning patterns. At present, the means to approach this issue is through qualitative observations and analysing arguments. Future research should focus on developing ways to identify the types of premises used for generating ideas and other types of design activity. This could take the form of retrospective analyses or automated methods that can identify different premises *in situ*.

Relationship between reasoning and mental models

A different approach to further investigating the argumentative aspect of design reasoning is the analysis of the mental models held between members of design teams in relation to reasoning patterns identified (Badke-Schaub *et al.*, 2007). Such an analysis could provide insights into coordinated or shared group understanding of what a design task is, which has been shown to influence performance (ibid.). Further, such studies should aim to relate reasoning patterns to concepts of team mental models to improve understanding of the phenomenon and to allow the development of methods to support practice.

Cultural differences and personal styles in reasoning

As mentioned in the limitations, differences are likely to exist in methods of reasoning across individuals and cultures. While the present research found the patterns of reasoning to be very robust, further research could address

this point. To better understand how reasoning might be different in other contexts, the use of work on cognitive styles (Durling *et al.*, 1996) or drawing on established work on cultural differences (Hofstede, 1984) might reveal answers in this regard.

Concluding the possible directions for further research, the final chapter briefly concludes the thesis.

7 ABBREVIATED CONCLUDING REMARKS

This chapter presents the final summary of the research presented. For more in-depth discussion and presentation of research results, contributions, limitations and avenues for further research, please refer to chapter 5.

The research presented in the thesis concerned the identification and analysis of reasoning patterns in design activity at a stage of group idea generation. The analyses and identification of patterns of reasoning help to illuminate design activity and how different types of activity influence the creative process and the value of design outcomes.

A method of analysis of verbal reasoning was developed to empirically identify reasoning patterns by using definitions of abductive, deductive and inductive reasoning types.

Two studies with experienced participants working on realistic or real-life design tasks were conducted to address overarching research issues. This method permitted an identification of reasoning patterns that differed from existing studies by recognising that different types of reasoning occur in chains of micro-inference and that verbal reasoning is disorderly and draws on premises from established facts, beliefs, and desires.

Using this method, it was possible to identify reasoning patterns that have significant effects on design activity and value. Specifically, the research uncovered a general and robust reasoning pattern comprising abductive-deductive interactions. Three further patterns were found to significantly influence design activity, in terms of short-term effects, long-term effects in idea generation processes, and value to outcome.

The work contributes to existing research by providing an empirical understanding of reasoning. It provides design practice with a foundation for developing guidelines, tools or methods that can aid facilitators of creative processes and to develop automated tools that can monitor and predict design activity *in situ*.

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A critical stage of design activity is the idea generation phase where groups of relevant people meet and create ideas for new solutions. Ideas developed here often have a major impact on the final product, as it is at this time that the space and frame for continuing design work is defined.

This thesis analyses how reasoning types appear in patterns when looking into what is being said and argued for in teams as they develop ideas and shows correlations between these patterns and the quality that the design team later determines the ideas to have.

Results show different, robust reasoning patterns occurring between exploring these perspectives and creating concrete solutions that influence idea generation activity and the value of outcome ideas to the continued design process.

The research has implications for the way argumentation and verbalisation of design ideas can be perceived to influence design activity and provides a foundation for educating designers, developing design support tools and by showing evidence for the argumentative nature of design.