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Barriers and enablers for the adoption of sustainable design practices using new design methods – Accelerating the sustainability transformation in the manufacturing industry☆

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ABSTRACT

Product development and manufacturing organizations struggle in their sustainability transformation and do not sufficiently contribute to sustainable production and consumption. Design researchers, at the same time, develop and propose a plethora of new and improved design methods that can support the manufacturing industry in such transformation. It is, despite this, well-documented in literature that the industrial adoption of such proposed design methods is challenging. Previous research in the design domain has mainly studied this issue from a process and methodological perspective, whereas previous research in the management domain instead has focused on organizational, and human-behavioral aspects. This poses a research gap for more interdisciplinary research that studies the adoption of design methods from all three perspectives (i.e., process and methodology, organization, and human behavior). Six parallel case studies were carried out with three different product development and manufacturing organizations to collect qualitative empirical data. Glaserian grounded theory was used to analyze the collected data. This resulted in a descriptive framework that captures 53 interdisciplinary factors influencing the adoption of sustainable design practices using new and improved design methods. The descriptive framework is compared to interdisciplinary literature to further clarify and explain the findings, highlighting both practical and theoretical implications. This research provides three main contributions to theory and practice: (1) Two new concepts are introduced and used to explain the empirical findings, which are referred to as the *dualism of design methods*, and the *situational design problem*; (2) Nine systemic barriers and eight propositions are formulated, which highlight the need for a paradigm shift in how design is practiced in industry, how *cognitive biases* inside organizations can lead to a state of *pseudo-sustainability,* and the need for improved information and data management capabilities in organizations; (3) *Sustainable design thinking* is proposed as an potential enabler to address several of the main barriers, as it aims to provide a base competence of sustainable design to systematically challenge *cognitive biases* inside organizations.

1. Introduction

There is a growing attention and consensus regarding the need for a so-called *sustainability transformation* in the product development and manufacturing industry, i.e., new product development efforts that contribute to sustainable production and consumption (see e.g., Bengtsson et al., 2018). *Design*, or *design practices* (see e.g., Cross, 1992; Dorst and Cross, 2001; Dorst, 2011), have both been highlighted to contribute to and strengthen organizations' innovation capabilities (see e.g., Micheli et al., 2018; Verganti et al., 2021), and critical in the *sustainability transformation* (Klotz et al., 2018; Sumter et al., 2020; Baldassarre et al., 2020), i.e., *sustainable design*, or *sustainable design practices*. Furthermore, previous research has shown that the appropriate adoption[1] of 'new and improved', or 'evidence-based', design

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[1] Adoption is here defined as "accepting or starting to use something new" (Cambridge, 2024). Adoption can however be partial, meaning that instances or facets of a design method are adopted.

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methods proposed by design researchers can support product development and manufacturing organizations to develop such capabilities and transform their current design practices into sustainable design practices (Faludi et al., 2020; Hallstedt et al., 2023a). Such organizations are, despite the pressing need, not able to appropriately adopt such proposed design methods (Karlsson and Luttropp, 2006; Baldassarre et al., 2020; Faludi et al., 2020) and struggle to integrate social, economic, and ecological perspectives in their current design practices (Vilochani et al., 2024). Moreover, the early design phases have been highlighted as critical where the ability to anticipate sustainability performance (i.e., both social, ecological, and economical) and design products with a lifecycle perspective is considered crucial (Bhander et al., 2003; Ramani et al., 2010; Hallstedt et al., 2023b). A research project, spanning over two years, was therefore initiated with several Swedish product development and manufacturing organizations, which focused on demonstrating these organizations' ability to adopt sustainable design practices using 'new and improved' design methods proposed by design researchers. Six parallel case studies were carried out in the early design phases across these organizations to collect empirical qualitative data, using participant observation (Säfsten and Gustavsson, 2020).

The industrial adoption of 'new and improved' design methods proposed by design researchers has historically been considered low (see e.g., Araujo et al., 1996; Wallace, 2011; Gericke et al., 2020). Gericke et al. (2020) claim that design methods are used in conjunction with other design methods, and introduce the concept of *method ecosystem*, which refers to the unique process and methodological context of an organization, and argue that proposed design methods must be adapted and fit into this context. A recent study (Parolin et al., 2024) focuses on sustainability assessments in the early phases of design and they provide several "design propositions" on how sustainability assessments can be carried out in these phases, such as using qualitative indicators. Similar to the literature listed above, much of previous research focuses on the industrial adoption of design methods from a process and methodological perspective, and fewer contributions can be found that provide insights regarding human-behavioral and organizational aspects (López-Mesa and Bylund, 2011; Booker, 2012; Pieroni et al., 2019). Such literature is what we in this paper broadly categorize and refer to as literature in the design domain, where a 'pragmatic approach' is common and results in proposals on how design methods can be modified, or 'improved', to meet the needs of practitioners and fit an organization's current design practices, or *method ecosystem*. Furthermore, what we instead broadly categorize and refer to as literature in the management domain has, on the other hand, had more focus on organizational and human-behavioral aspects. There is a research gap and need for interdisciplinary research that explores and bridges these domains and frames the industrial adoption of design methods from all three perspectives. The following research question was thus formulated to capture all three perspectives during the empirical data collection:

- What influences the adoption of sustainable design practices using new and improved design methods?

Glaserian grounded theory (Walker and Myrick, 2006; Charmaz, 1996) was used to analyze the data and resulted in a descriptive framework that frames 53 interdisciplinary factors. The framework is also compared to interdisciplinary literature to further clarify and explain the empirical findings. The main contribution of this study serves as the base for new practical and theoretical insights towards:

(i) How to facilitate and increase the adoption of new and improved design methods.
(ii) How new and improved design methods can support practitioners in their organization's *sustainability transformation*.

The remainder of the paper is structured as follows: Section 2 provides the theoretical background within the studied topic; Section 3 presents the research methodology focusing on the research context, and how qualitative data was captured and analyzed; Section 4 presents the results from the analysis as a descriptive framework along with two new concepts; Section 5 provides a comparison between the empirical findings and literature to highlight the theoretical contributions and the main implications on practice; Section 6 provides conclusions and key points to research and practice, along with future work.

2. Literature review

This paper adopts an interdisciplinary focus, and Section 2 aims to provide readers from different disciplines with sufficient literature and background of all three perspectives (i.e., process and methodology, organization, and human behavior) to follow the reasoning throughout the paper. Section 2.1 provides theoretical background to design and designing, and the focus of this study. Section 2.2 provides the utilized lens for sustainable design practices. Section 2.3 presents a theoretical background to design methods and why they are relevant to practitioners. Section 2.4 provides a set of theories later used to explain the empirical findings, enabling us to bridge the identified research gap.

2.1. Design and designing

There have been many claims of what *design*, or *designing*, is (see e.g., Asimow, 1962; Jones, 1970; Schön, 1992). Simon (1969) stated that "everyone designs who devises courses of action aimed at changing existing situations into preferred ones" and that designing "is concerned with how things ought to be, with devising artifacts to attain goals". We view designing or any design process as a knowledge-producing process, where different design activities support designers to better understand the problem at hand as well as the potential solutions to that problem, and the overall goal is to identify a good problem-solution fit (Cross, 1992; Dorst and Cross, 2001; Dorst, 2006). Dorst and Cross (2001) refer to this as the *co-evolution of problem-solution*, which clarifies the iterative nature of design where both the problem and solution spaces evolve as we learn more about the problem and its potential solutions.

Eder (1998) divides a design process into the four generic phases of (i) understanding the problem, (ii) conceptualizing, (iii) embodiment, and (iv) detailing, and refers to (i) and (ii) as the "early stages of designing", which is the focus of this study. Here, design freedom is high, but less is known, and uncertainty is high, which results in a well-known dilemma referred to as the *design process paradox* (Ullman, 1992; Bhander et al., 2003; Chebaeva et al., 2021). *Front-loading* is a common strategy to counter the *design process paradox*, where the goal is to push knowledge generation as early as possible in the design process (Thomke and Fujimoto, 2000) and become critical to develop and propose more sustainable solutions (Bhander et al., 2003; Ramani et al., 2010; Hallstedt et al., 2023b).

A design process is typically needed to treat *design problems*, i.e., ill-structured, ill-defined, wicked, and unique problems (Simon, 1969; Rittel and Webber, 1973; Archer, 1979; Buchanan, 1992; Dorst, 2006; Gericke et al., 2022). *Design problems* are for example characterized as not having a single solution, unknown before the design process, and unique (Rittel and Webber, 1973; Buchanan, 1992). There have also been claims that *design problems* are paradoxical in the sense that designers do not know the 'real' *design problem*, or at least do not fully understand it before they have engaged in the early phases of design (Archer, 1979; Dorst, 2006). Potential solutions (i.e., 'products', 'designs', or 'artifacts') to such *design problems* are not obvious and benefit from applying *designerly ways of knowing* (Cross, 1982). *Design problems* can, for example, relate to 'how to transport users from A to B', 'how to design a lightweight airplane foil', 'how to design a circular supply chain', or 'how to design a music festival'. The paradigm of *design thinking* (Brown, 2008) has, for example, effectively utilized these insights of design or *designerly ways of knowing, thinking, and acting* (Cross, 1982; Cross, 2023) to revolutionize problem-solving activities on a broader level outside of its origin within architecture and product design (Verganti et al., 2021; Auernhammer and Roth, 2021). To summarize, this sub-section underpins why *design*, or *design practices*, can be effective when solving complex problems related to sustainable development.

2.2. Sustainable design practices

Baldassarre et al. (2020) broadly define sustainable design as “the rational and structured process to create something new for solving sustainability-related problems” and argue that a complete transformation to *sustainable design practices* is a matter for the whole organization. Sala et al. (2015) highlighted the challenge of understanding “what contributes to a sustainable development and what does not”. Our study utilizes the *Framework for Strategic Sustainable Development* (FSSD) (see e.g., Broman and Robèrt, 2017) to frame how design, or *sustainable design*, can contribute to sustainable development. Included in the FSSD are for example eight principles that define socio-ecological sustainability that need to be considered throughout a design’s, or product’s, full lifecycle to contribute to sustainable development. These eight principles are explicitly defined (Broman and Robèrt, 2017): “In a sustainable society, nature is not subject to systematically increasing…

1. Concentrations of substances extracted from the Earth’s crust.
2. Concentrations of substances produced by society.
3. Degradation by physical means.

And people are not subject to structural obstacles to

4. Health.
5. Influence.
6. Competence.
7. Impartiality.
8. Meaning-making.”

The FSSD also provides guidelines on how to adopt a strategic approach towards sustainable development. This includes the use of a forecasting and backcasting approach: (i) The vision is identified and formulated; (ii) The barriers to realizing the vision are identified and formulated; (iii) The required steps to reach the vision are identified and formulated; (iv) The different steps are prioritized. To summarize, we outline the following definition of *sustainable design practices* in this paper:

> The appropriate incorporation of the *Framework for Strategic Sustainable Development* and *designerly ways of knowing, thinking, and acting* in an organization’s design process.

Adopting *sustainable design practices*, in turn, strives to ensure that the developed solutions comply with the eight socio-ecological principles of the FSSD throughout their full lifecycle, and across the full value chain. This is, however, challenging and requires appropriate skills, knowledge, and the adoption of several design methods (Faludi et al., 2020; Hallstedt et al., 2023a).

2.3. Design methods and their role to designers

Design methods are one of the main study objects in our study and a term both referred to and used differently across research domains (see e.g., Bunge, 1966; Layton Jr, 1974; Niiniluoto, 1993; Araujo, 2001; Van Aken, 2004; Gericke et al., 2022). Cross (2000) broadly claimed that “in a sense, any identifiable way of working, within the context of designing, can be considered to be a design method”. Jones (1970) argued that design methods are “attempts to make public the hitherto private thinking of designers; to externalize the design process” and Eder (1998) also describes them as “prescriptive knowledge as advice about designing (‘know-how’)”. Wallace (2011) defines a design method as: “a prescriptive plan of action by which a class of design tasks are tackled”. Moreover, Daalhuizen and Cash (2021) stated that a design method is an encapsulation of procedural knowledge key to designing and the design process. Gericke et al. (2022) provide further nuance to what design methods are:

> “A specification of how a specified result is to be achieved. This may include specifications of how information is to be shown, what information is to be used as input to the method, what tools are to be used, what actions are to be performed and how, and how a task should be decomposed and how actions should be sequenced”.

To summarize, design method(s) as an umbrella term can thus generally be considered wide in what it covers, where different design methods treat different aspects of design, such as sustainability performance. They also apply to different situations, such as early phases, and types of products, or artifacts. We argue that the role of any design method is to prescriptively guide designers in generating a set of specific knowledge related to the ‘*design problem* at hand’ (e.g., ‘how to transport the user from A to B’, or ‘how to design a lightweight airplane foil’). In turn, design methods support designers in meeting the overall goal of designing, which is to identify a good problem-solution fit (Cross, 1992; Dorst and Cross, 2001; Dorst, 2006).

2.4. Adoption of design methods and perspectives on managing change

Design as a research domain, see e.g., Blessing and Chakrabarti (2009) and Gericke et al. (2022), proposes a plethora of, rigorously verified, new, and improved prescriptive design methods, and are occasionally also referred to as ‘formalized’, ‘theory-based’ and/or ‘industry best’ practices (Eder, 2009). Such design methods are typically developed and proposed to the industry by a design researcher where the *Design Research Methodology* is commonly used (Blessing and Chakrabarti, 2009). The adoption of such new and improved design methods proposed by design researchers has, however, had a low industrial uptake (Karlsson and Luttropp, 2006; Booker, 2012; Gericke et al., 2020; Faludi et al., 2020). The main reasons for the low uptake or adoption are summarized by Wallace (2011) explicitly:

(i) Methods tend to be too complex, abstract, and theoretical.
(ii) Too much effort is needed to implement them.
(iii) The immediate benefit is not perceived.
(iv) Methods do not fit the needs of designers and their working practices.
(v) Little or no training and support are provided by companies.

Wallace (2011) does however also point out that designers do use design methods but often implicitly. Eder (1998) emphasizes the need for adapting proposed design methods and adds that practitioners need to claim ownership of design methods and refer to individuals who champion the design method inside an organization. Eder (2009) later refers to the concept of a *method expert*, which is an individual who has enough experience, competence, and understanding of the design method to ensure it is used as intended, and the term will later be used when referring to our study objects. Previous research provides several relevant insights concerning the challenges of adopting new and improved design methods proposed by design researchers in industry. However, adopting new and improved design methods requires further understanding and consideration of organizational, and human-behavioral aspects (López-Mesa and Bylund, 2011; Booker, 2012; Pieroni et al., 2019). A set of concepts related to these perspectives are therefore briefly presented below and are later used in Section 5 to further highlight the need for considering all three perspectives, i.e., process and methodology, organization, and human behavior when studying the adoption of sustainable design practices using new and improved design methods.

Hackman and Oldham (1976) studied human-behavioral aspects concerning motivation and acceptance of new practices. They identified autonomy as a critical component to ‘work design’ and defined *autonomy* as “the degree to which the job provides substantial freedom, independence, and discretion to the individual in scheduling the work and in determining the procedures to be used in carrying it out”. The role of autonomy has been studied further, and Deci et al. (2017) argue in their *Self-Determination Theory* that basic psychological needs in work design are autonomy, competence, and relatedness. Furthermore, Kotter (1995) proposes one influential, but occasionally criticized (see e.g., Appelbaum et al., 2012), model on organizational change. Several recommendations are provided where, for example, the importance of involving people in the change process is emphasized. Kotter (2012) elaborates on Kotter’s eight-step model and argues that the initial reason why change fails is due to complacency. Samuelson and Zeckhauser (1988) also emphasize that change is challenging in their *status quo bias in decision making* and that it is both easier, and common, to “doing nothing or maintaining one’s current or previous decision”.

Agency theory (see e.g., Ross, 1973; Mitnick, 1973; Eisenhardt, 1989) has been widely studied but in different research streams using different schools of thought and generally accounts for action in the relation between actors (i.e., principal-agent) and how it, for example, is influenced by e.g., bounded rationality, self-interests, and/or conflicting goals (Eisenhardt, 1989; Mitnick, 1992; Shapiro, 2005). The concept of *Bounded rationality* (Simon, 1969) can briefly be described as humans being biased and unable to make optimal decisions but rather making decisions that are satisfactory due to cognitive barriers i.e., satisficing. As a result, humans tend to use *heuristics*, or ‘rules of thumb’ in design, or ‘complex problem-solving activities’ (Simon, 1979). Simon (1969) elaborates on heuristics:

> “Heuristic methods provide an especially powerful problem-solving and decision-making tool for humans who are unassisted by any computer other than their own minds, hence must make radical simplifications to find even approximate solutions”.

In our study, it is important to acknowledge that some accounts treated in agency theory share similar traits to what others have referred to as cognitive barriers or *cognitive biases*, and are of relevance (Mitnick, 1992). Mitnick (2019) also explicitly stated, in a non-peer-reviewed paper, that “people make decisions based on things like norms, information with social origins, and what more recent literature terms cognitive heuristics or biases”. The presence of norms or informal rules in organizations is further treated in works related to *Institutional theory* (see e.g., Meyer and Rowan, 1977; DiMaggio and Powell, 1983). DiMaggio and Powell (1983) explain institutions and introduce the concepts of *institutional rules* and *institutional isomorphic change* which govern how organizations behave, or act, and change according to norms and informal rules. To summarize, several theories can explain the underlying reasons for several barriers and enablers of the studied topic and will be further revisited in Section 5.

3. Research methodology

This research encompasses a large empirical study utilizing a multiple case study approach (Säfsten and Gustavsson, 2020), and the overarching research methodology is visualized in Fig. 1. This figure highlights the different activities (grey boxes), in- and outputs, and approximate order. Six industrial case studies (denoted as A1, A2, B1, C1, C2, and C3) were carried out during a two-year research project together with three Swedish product development and manufacturing organizations. Each of the case studies had a different sustainable design scope, further described in Section 3.2. The research project as such focused on demonstrating these organizations’ ability to adopt *sustainable design practices* using new and improved design methods proposed by design researchers. This allowed us to the socio-technical interplay between design researchers, practitioners, and design methods using participant observation (Säfsten and Gustavsson, 2020). This is further described in both Sections 3.2 and 3.3. In turn, this resulted in the

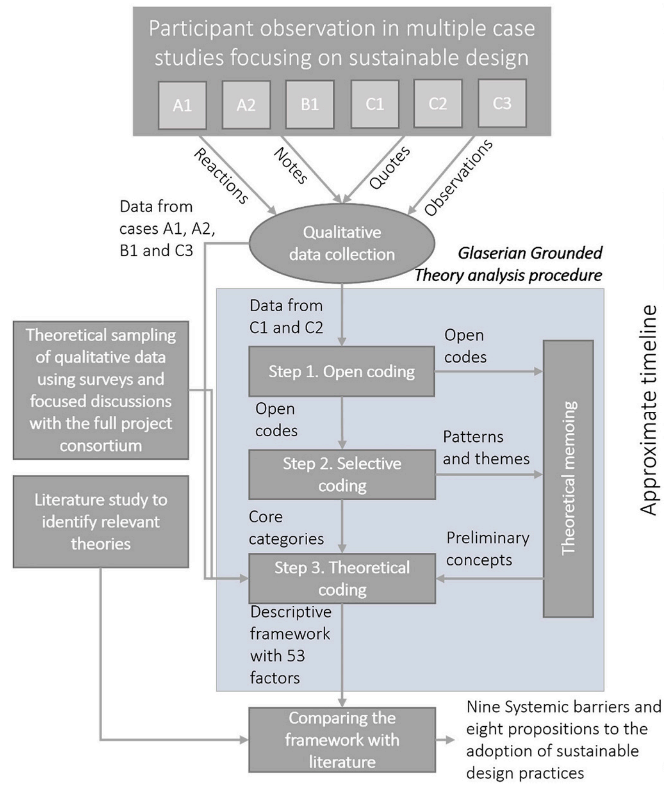

Fig. 1. Applied research methodology highlighting the analysis procedure, supplementary activities, and in/outputs.

collection of a large set of qualitative data (Säfsten and Gustavsson, 2020) relevant to the scope and the formulated research question in this paper. As visualized in Fig. 1, different types of qualitative data were collected from the six case studies and are further described in Section 3.3. The data was collected using different activities in the multiple case studies and is further described in Section 3.2. Glaserian grounded theory (Walker and Myrick, 2006) was identified and chosen as an appropriate method for analyzing the collected qualitative data, and developing a descriptive framework. Charmaz (1996) describes Grounded theory as a set of inductive strategies for analyzing data, which can be used to synthesize, explain, and understand the collected data. It builds on both interpretative as well as positivist assumptions and has a strong history in qualitative research, which allows both different and novel themes to emerge. It can also support making conceptual sense of large sets of qualitative data. As visualized in the surrounding blue box in Fig. 1, the analysis procedure and development of a descriptive framework using Glaserian Grounded Theory followed three main steps: (1) Open coding; (2) Selective coding; (3) Theoretical coding (Walker and Myrick, 2006). The first coding step captured several different aspects related to the adoption of sustainable design practices from one or more of the three perspectives (i.e., process and methodology, organization, and human behavior). The latter two coding steps further nuanced these aspects, which resulted in a final descriptive framework consisting of 53 interdisciplinary factors that influence the adoption of sustainable design practices using new and improved design methods. The analysis procedure is further described in Section 3.5 and provides further clarity on how the codes as such relate to the adoption of sustainable design practices. Additionally, the developed framework was lastly compared with the literature provided in Section 2 to further nuance and explain the findings, which is also visualized in Fig. 1. Altogether, the research methodology supports fulfilling the explorative and interdisciplinary scope of our study, making it a suitable choice. The sub-sections below are dedicated to describing the analysis procedure and other relevant aspects related to the research methodology in more detail. This includes the utilized design methods, the industrial cases, the data collection, and the limitations of the study.

3.1. Design methods used in the multiple case study

The design methods used in the multiple case studies are divided into two categories in this paper.

Category one: Systems Engineering Design (SED) design methods, based on more than 20 years of research in close collaboration with the Swedish product development and manufacturing industry (see e.g., Isaksson et al., 2000; Isaksson et al., 2013; Borgue et al., 2021). The SED design methods aim to support the modeling and design of complex systems or designs where there are several dependencies and interactions between different domains and sub-systems (e.g., functions in the system, stakeholders in the system, and/or engineering disciplines utilized in the system). These dependencies are evaluated jointly in the early phases of design, which ultimately supports practitioners in assessing the impacts of different design decisions on complex socio-technical systems (Isaksson et al., 2023). Applying the SED design methods typically involves the collection of data and information from different stakeholders in the organization which is later incorporated and/or modeled in computer-based tools by either a design researcher or practitioner, i.e., a *method expert*. The outcome is later communicated and utilized across organizations to enable more information-based design decisions.

Category two: Sustainable Product Development (SPD) design methods and are based on more than 15 years of research in close collaboration with the Swedish product development and manufacturing industry (see e.g., Byggeth and Hochschorner, 2006; Hallstedt et al., 2013; Watz and Hallstedt, 2022). The SPD design methods aim to support the strategic integration of socio-ecological sustainability, using the FSSD (Broman and Robèrt, 2017), in product development and manufacturing organizations by ensuring that a full systems perspective is incorporated in the early phases of design. The design methods support practitioners in e.g., anticipating the sustainability performance of different solutions, identifying sustainability-related risks, and guidance towards more sustainable solutions. Applying the SPD design methods typically involves a 2–3 h facilitated workshop using a multidisciplinary team of practitioners, including different designers, experts, and/or specialists inside the organization, where a set of key questions or focused topics are discussed. This information is later consolidated either by design researchers or practitioners, i.e., a *method expert*, and the outcome is typically communicated and used by relevant stakeholders inside and outside the organization.

3.2. Case companies and activities in the multiple case study

Three different Swedish companies in three different sectors were used in the multiple case studies. The case companies are suitable choices as they represent: (i) International product development and manufacturing organizations; and (ii) Organizations that have an expressed ambition to design and manufacture more sustainable solutions, and thus transform their current design practices into *sustainable design practices*.

Company A is a large first-tier supplier that develops and manufactures integrated metallic and composite assemblies for aero-structures and aero-engine products. Two case studies were carried out with Company A, both focusing on the sustainable industrialization of additive manufacturing. The cases were with different scopes and performed with different functions within the organization but both within the context of technology integration and development.

Company B is a semi-large product development and manufacturer of sealing solutions for the telecom, manufacturing, and construction industries. This case focused on sustainability governance and how to integrate sustainability in their product innovation process, where a steel frame was used as the case product.

Company C is a large product development and manufacturing company in the automotive sector. Three different cases were carried out with this company, but two had several joint activities, namely cases C1 and C2 (see Table 1). The scope of these was deemed to be aligned and required tighter collaboration between the two business functions (product design, and procurement and sourcing). This required participants from several different functions since product design and procurement and sourcing are treated as two different business units within the same company. The third case from this company came from a third business unit and was treated as a separate case study.

The case studies represent six different design scopes and five different organizational functions, as illustrated in Table 1. The design methods applied in each case study were identified together with the industrial practitioners individually for each case, i.e., which design methods were deemed to suit the challenges addressed in the design scopes. Each of the six cases involved more than 10 different industrial participants and five different design researchers. Furthermore, as visualized in Fig. 1, the research project and its six parallel industrial case studies (A1–2, B1, and C1–3) served as input for collecting relevant qualitative data for two years, and in four distinct ways:

(1) A total of 33 workshops were carried out across the six case studies and corresponded to the appropriate use of many of the proposed design methods, as described in Section 3.1.
(2) Recurring bi-weekly meetings varying between 30 and 45 min were held with each company to coordinate the activities carried out in the case studies. These meetings were, for example, used to ensure that relevant industrial participants took part in the workshops and that appropriate data and information were at hand in the workshops or fed into the design methods. These also involved practitioners elaborating on issues they are facing regarding their sustainability transformation.
(3) Four large seminars were carried out in the research project with the full project consortium that consisted of an additional four product development and manufacturing organizations, and two product development consultancy organizations. The seminars included several emerging topics concerning the research question and were discussed in larger workshop formats.
(4) More than ten surveys were sent out either during or in preparation for the four seminars to obtain individual practitioner responses on the topics discussed during the seminars. Qualitative data was collected as practitioner responses in the shape of free-form text.

Both design researchers and practitioners were treated as study objects since they both are considered stakeholders relevant to the research question. Practitioners served as the practitioners or users of the design methods while also representing the organizations' challenges towards a *sustainability transformation*. The design researchers were divided into two roles, both as *method developers*, i.e., the ones that have developed the design method, but also as the role of *method experts*. It is not necessarily the design researchers who take the role of *method experts* but took this role in many instances since most of the design methods are new to the organizations. Moreover, it was thus also in most instances the *method developers* i.e., the design researchers, who proposed the design methods to the organizations according to their expressed challenges in this study.

3.3. Qualitative data collection using participatory observation

One researcher, who had no prior experience in using the proposed design methods, took part in 30 out of the 33 conducted workshops, and all four seminars. This researcher also acted as coordinator of the six parallel case studies and thus participated in most of the informal meetings. In turn, qualitative data was collected using *participant observation* (Säfsten and Gustavsson, 2020). Furthermore, the degree of

Table 1
Case descriptions.

Case	Company	Context	Design scope	Conducted workshops	Nr. of different SED methods applied	Nr. of different SPD methods applied
A1	A	Technology integration and development	Sustainable design of a turbine rear structure using laser powder bed fusion	2 separate, and 2 joint with A2	1	3
A2	A	Technology integration and development	Sustainable repair of a fan blade with direct energy deposition	2 separate, and 2 joint with A1	–	3
B1	B	Management and product design	Strategically integrating sustainability in the product innovation process of a steel frame	8 separates	–	5
C1	C	Product design	The sustainable and circular design of a seat in the new generation of electric vehicles	10 joint with C2, and 1 joint with C2 and C3	3	6
C2	C	Procurement and sourcing	Sustainable and circular supply chains for a seat in the new generation of electric vehicles	1 separate, 10 joint with C1, 1 joint with C1 and C3	3	6
C3	C	Material and product design	Sustainable material selection for a cable bracket component	7 separate, and 1 joint with C1 and C2	1	3

participation was *moderate* where "the observer balances between being an insider and an outsider, between participation and observation" (Säfsten and Gustavsson, 2020). Qualitative data was collected during workshops, seminars, and informal meetings, and in most instances in line with what can be defined as *qualitative observations* (Creswell, 2014) and what Säfsten and Gustavsson (2020) refer to as *direct* and *unstructured* in the format of in-vivo (Miles et al., 2014) in notebooks. The collected qualitative data was, however, not only in the form of qualitative observations and was deemed to be distinguishable into four different types:

(1) Quotes: either from a design researcher or a practitioner.
(2) Observations: Concrete events or observations that occurred, either by a design researcher or practitioner.
(3) Notes: Either something a design researcher or practitioner said or presented but not captured how it was explicitly phrased and are therefore separated from quotes. It also relates to assigned 'action points', either by a design researcher or practitioner.
(4) Reactions: The observer's reaction to observations, which resulted in either a 'thought' or 'idea' related to the topic that is studied.

One example of each type of collected data is provided in Table 2.

Qualitative data was also collected using surveys via online survey tools. Data was collected for almost two years and resulted in almost five full notebooks, where each included 192 A5 pages of qualitative data. The collected data captured aspects relevant to the topic and included both process and methodological, organizational, and human-behavioral aspects.

3.4. Limitations of the study

Three main limitations can be linked to this study: (1) A large amount of data was generated, a recurring dilemma in Glaserian Grounded Theory due to its explorative nature (Cutcliffe, 2000). The data used in steps one and two was therefore strictly limited to cases C1 and C2 and for a fixed period to avoid biased selection of data; (2) The data was collected during specific occasions in a research project, as specified in Section 3.2, and not within the daily operations of the organizations and can influence potential claims. The appropriate use of the design methods was however studied in real cases as part of in-house projects in the organizations; (3) One individual researcher oversaw data collection and the Glaserian grounded theory analysis. A correspondence criterion was therefore used throughout the coding process, and steps one and two were also rigorously checked by two researchers to reduce the risk of bias. The overall procedure is further clarified below.

3.5. Analysis of empirical data using Glaserian grounded theory

As mentioned, Glaserian grounded theory was used to analyze the empirical data, as visualized in Fig. 1, and is separated into three main steps (Walker and Myrick, 2006): (1) Open coding; (2) Selective coding; (3) Theoretical coding. Moreover, three guiding principles were used to preserve the interpretative and positivist assumptions of Glaserian grounded theory (Åge, 2011):

(1) The codes correspond to the data (positivism).
(2) The data is interpreted and understood in its context when assigned codes (hermeneutics).
(3) The codes are useful (pragmatism).

3.5.1. Open coding of case studies C1 and C2

Before the open coding could be carried all collected data from case studies C1 and C2 was inserted manually from the notebooks into Excel to ease the coding process. The open coding later began by assigning individual meaning, i.e., open codes, to each line of the collected data line by line and comparing them to each other. Approximately 220 lines of data captured in the Excel file were analyzed and resulted in roughly 200 open codes and two examples from the analysis are presented in Table 3.

In example one, see Table 3, row two, data was captured in an informal meeting with company C where a practitioner elaborated on

Table 2
Examples of collected data for each type.

Types of collected qualitative data	Example of how it was explicitly captured in the notebook	Context of where data was collected
Quote	"The participating practitioners want to know they will get 'something out' from taking part in the workshops"	This was a quote by one practitioner during an informal coordination meeting
Observation	Difficult to comprehend/limit the discussion related to the specific case product	This observation was captured during the use of one of the design methods focusing on assessing the sustainability performance of the case product
Note	Must check what data we already have that can be used, and then 'bounce it' with the company coordinator	This was a note related to planned activities to be carried out with one of the case companies
Reaction	Do the customers even want to have transparency? They might be shocked when they see the social issues in the value chain	This was a reaction noted down during a workshop focusing on assessing the sustainability performance of on case product.

Table 3
Examples from the open and selective coding procedure.

Context	Date	Note	Open coding	Selective coding
Informal meeting with company C - Procurement and sourcing	210614	Practitioner: *Need to work in new ecosystem to work "circular" *See a need of a new system *Various of different new issues "1000's" *Traceability, several actors -> need to ensure "waste" is managed -> How do we even start this collaboration	There is a need to collaborate with actors differently to develop more sustainable solutions	New sustainable design practices
WS at company C where they present the case product for C1 and C2	220310	Development of product -Product breakdown -> different view -Core structure *Comfort system *Safety system *Custom specific -Product one of the most complex parts *Legal *Safety *Integrate many things -Scalable	There is a need for design researchers to understand the case product	Method experts' understanding of company case and context

issues and challenges related to the design of circular supply chains. The open code ("there is a need to collaborate with actors differently to develop more sustainable solutions") was assigned by interpreting and understanding the data based on who was involved and the activity (Context and date), together with what happened and/or what was said. This is also in correspondence with what the original data stated and useful to the research question. In the second example, see Table 3, row four, data was captured during a workshop arranged at company C for practitioners and design researchers involved in C1 and C2. The workshop focused on presenting the product used in the case study, and the data related to the product itself. The open code ("there is a need for design researchers to understand the case product") was assigned based on interpreting and understanding the data. This followed the principles above and is both in correspondence to the original data and useful to the research question.

3.5.2. Selective coding of case studies C1 and C2

The selective coding focused on identifying core categories based on the already identified open codes, where each open code was assigned a selective code with a higher abstraction level. Charmaz (1996) refers to this as "a category may subsume common themes or patterns in several codes", and two examples of this are provided in Table 3, column 5. The selective coding was carried out after the open coding was completed, but patterns and themes started to emerge during the open coding. The first selective code, or core category, was generated based on the first line of open code, and every open code that fit within that core category was assigned to it. New core categories were identified and formulated whenever the current set of core categories had a poor fit to an open code. Furthermore, open codes can be assigned to several core categories, which in turn meant that whenever a new core category was identified it also iteratively had to be compared to previous open codes to check potential fit. Eight core categories were generated in total, and these are presented in Table 4.

3.5.3. Theoretical coding of collected data

Theoretical memos were continuously formulated throughout the open and selective coding process, as visualized in Fig. 1. Such memos refer to preliminary ideas, or sub-concepts, captured as short sentences, and saturate and converge over time (Walker and Myrick, 2006). The theoretical coding as such later focused on iteratively going back and forth between the raw data, open codes, core categories, and theoretical memos. This step conceptualizes and frames how the open codes and core categories relate to each other (Walker and Myrick, 2006). Furthermore, data captured from the remaining cases (A1–2, B1, and C1–3) and additional sources, such as the surveys, were also used as input to the theoretical coding. This is also visualized in Fig. 1. Charmaz (1996) refers to this step as theoretical sampling, i.e., "collecting more data to clarify your ideas and to plan how to fit them together". No additional core category was identified, but this instead generated more open codes related to the core categories, which in turn:

(i) Further clarified the core categories and additional relations between core categories.
(ii) Strengthened the core categories and the identified relations.
(iii) Added further depth to the core categories and the relations.

The results from the theoretical coding are captured in a descriptive framework that frames 53 interdisciplinary factors, and a summarizing table, presented in Section 4. Additionally, the full analysis of the theoretical coding is provided as supplementary information.

Table 4
Core categories generated during the selective coding.

	Core categories	Frequency of core category in the open codes
A	Practitioners' understanding of why and how to use design methods	45
B	Method developers' understanding of practitioner needs	37
C	Design methods fit into the current design processes	44
D	New sustainable design practices	53
E	Method experts' understanding of company case and context	47
F	Practitioners' design method engagement	35
G	Design method synergy and integration	38
H	Information and data capturing in sustainable design practices	37

Table 5
The 53 factors captured by the descriptive framework.

Factor	Occurrence and degree of influence (see also Fig. 2)
F1: Lack of understanding leads to misuse	It was frequently observed that a lack of understanding of 'why and how' to use design methods had an impact on design method outcomes. In turn, this either had a reduced and/or negative impact on the sustainability performance of a solution and became a barrier to the center circle.
F2: Lack of understanding limits practitioner engagement	It was frequently observed that a lack of understanding of 'why and how' to use design methods resulted in decreased engagement by the practitioners. This factor becomes a barrier towards the center circle.
F3: There are difficulties in understanding how sustainability can be simplified	It was frequently observed that practitioners require or explicitly ask for some pragmatism in the context of sustainable design practices. This was typically addressed by simplifications or defining what they deemed as reasonable boundary conditions, i.e., narrowing the scope. It was, however, occasionally difficult to understand to what extent the scope could be narrowed, which led to design method outcomes that either had a reduced and/or negative impact on the sustainability performance of a solution.
F4: The concept of lifecycles is difficult to understand	Sustainable design practices require products to be designed for and assessed throughout all their lifecycle phases, i.e., material extraction to end-of-life and/or circular activities to extend the product's life or components life (e.g., repurpose or remanufacture). This challenged how the practitioners work at present, and it was frequently observed as difficult to either fully comprehend and/or practice this concept. This, in turn, becomes a barrier towards the center circle.
F5: Failing to meet needs limit adoption	Several of the identified factors relate to the different needs of the practitioners. Some needs were observed, but some needs were occasionally explicitly expressed needs by practitioners. Failing to meet either of these becomes a direct barrier towards the center circle.
F6: Need to understand how methods can be fitted into the current design processes	It was frequently observed that fitting design methods to companies' current design process needs to be considered when introducing new design methods to practitioners. It was in addition to this also frequently mentioned by practitioners as a core need. In turn, this becomes a barrier towards the center circle.
F7: Need to understand how practitioners currently work	It was frequently observed that there is a need to understand how practitioners currently work to ensure applicability. Failing to meet this need will limit adoption and can also result in instant rejection, becoming a barrier towards the center circle.
F8: Need to understand how to get practitioners' engaged	It was occasionally observed that it was not fully clear how to get practitioners engaged. Failing to engage practitioners can have consequences on different scales and is a barrier to the center circle.
F9: Need to be able to convey the 'why and how' to the practitioners'	It is not fully clear how to effectively, and efficiently, convey the "why and how" to use design methods since practitioners frequently require support in understanding the "why and how". Failing to meet this need results in either limited adoption and/or misuse. Successfully meeting this need can instead be an enabler towards the center circle.
F10: Adaptation is required	This barrier was constantly observed but to different degrees in terms of how much adaptation was needed. It could for example be that guiding questions in templates needed to be changed, that the representation of input- information and data needed to change, or that the scope and core idea of the design method had to be changed. In turn, this becomes a barrier towards the center circle.
F11: Sustainable design is considered complex and needs to be simplified	It was frequently observed that practitioners feel the need to simplify sustainability since it is a complex and systemic topic with many effects that are difficult to anticipate. This resulted in design method outcomes that, in turn, either had a reduced and/or negative impact on the sustainability performance of a solution and thus become a barrier towards the center circle.
F12: Increases if fitted into the current design process	It was frequently observed that if a design method was perceived as potentially possible to fit into the current design process, practitioner engagement increased and thus became an enabler towards the center circle.
F13: Limited if not fitted into the current design process	Practitioners frequently highlight the importance of being able to fit the design methods into the current design process and that adoption will be limited otherwise.
F14: Design process differs from company to company	It was constantly observed that the design processes differ from company to company, such as daily routines and design activities, available time and resources, competence, and the background of the design method user. This makes it difficult to ensure that design methods fit every individual design process since it will require some adaptation and thus becomes a barrier towards the center circle.
F15: The methods need to support challenges or 'problems' related to sustainable design practices	It was constantly observed that the design methods do support challenges or 'problems' related to sustainable design practices, which incentivized the practitioners to use the design methods. In turn, this becomes an enabler towards the center circle.
F16: Radical changes limit the ability to fit into the current design process	It was occasionally observed that the new sustainable design practices require larger or radical changes in how practitioners work today. One example relates to the sustainability criteria that the practitioner at this moment needs to consider in their early design phases, which currently (mainly) considers product material, geometry, and components. New sustainable design practices will however require the full lifecycle to be considered and designed for in the early design phases, and potentially circular services i.e., activities in the up- and downstream supply chains. In turn, this requires new types of input- data and information used in the design activities in the current design process and increases the scope of the design activities. Practitioners were occasionally observed as having reservations when the design methods were perceived as introducing such changes. In turn, this becomes a barrier towards the center circle.
F17: Requires new working practices and skills	It was frequently observed that new sustainable design practices require new working practices and skills. It was constantly observed that practitioners were reserved when the design methods signaled that new working practices needed to be introduced, and the practitioners would let the method experts know that 'this is not how we work today'. Furthermore, it was occasionally observed that there was a lack of certain specialist expertise required to use the design methods. It could either be that the practitioner required was unavailable due to limited time and prioritization or that the company lacked that role. It was frequently observed that there was a knowledge gap related to sustainability. In turn, this becomes a barrier towards the center circle.
F18: Sustainable design practices require the 'right' competence	Many of the new sustainable development practices in early phase design are qualitative design methods, and it was frequently observed that they require the 'right' competence when using the design methods. Using the design methods without the 'right' competence resulted in design method

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Table 5 (*continued*)

Factor	Occurrence and degree of influence (see also Fig. 2)
	outcomes that either had a reduced and/or negative impact on the sustainability performance of a solution, and thus becomes a barrier towards the center circle.
F19: Sustainability principles are not understood	It was frequently observed that core principles such as the three sustainability dimensions of social, ecologic, and economic along with a full lifecycle perspective are not well understood nor practiced at this moment. In turn, this resulted in design method outcomes that either had a reduced and/or negative impact on the sustainability performance of a solution and thus became a barrier towards the center circle.
F20: Methods require practitioners' engagement	It was constantly observed that the design methods require the practitioners' engagement. Practitioners were either required to perform certain actions and provide input- data and information or provide understanding such that method experts could perform tasks related to the design methods. In turn, this becomes a barrier towards the center circle.
F21: There is some awareness that sustainable design practices are needed	It was occasionally observed that the practitioners are aware that a transformation and change of practices are needed to develop more sustainable solutions. This had a positive influence on the incentives to use the design methods and thus became an enabler towards the center circle.
F22: There is limited sustainability relevant expertise	It was frequently observed that there is a lack of the sustainability-relevant expertise that is required in new sustainable design practices. There was expertise within niche sustainability topics such as environmental regulations, substances of concern, or corporate social responsibility processes. Sustainable design practices do however require other types of expertise as well such as cross-disciplinary expertise within both design and sustainability. In turn, a lack of this becomes a barrier to the center circle.
F23: Several methods are needed	It was constantly observed that the companies are facing several challenges or 'problems' related to sustainable design and that each design method only addresses a set of these challenges or 'problems'. Fitting several design methods adds complexity. In turn, this will become a barrier towards the center circle.
F24: Difficult to know which methods are needed	The case companies face several challenges or 'problems' related to sustainable design practices, and there are also several design methods developed to choose from. These design methods vary in scope along with their applicability to case and context. It was frequently observed as difficult for method experts to instantly know which design methods to use for the specific challenge or 'problem'. This becomes a barrier towards the center circle when combined with other barriers, such as F7 ("need to understand how practitioner currently work") and F33 ("difficult to get full understanding").
F25: There is a need to train and educate practitioners within sustainable design	It was frequently observed that the competence and knowledge within sustainability need to increase, which in turn becomes a barrier towards the center circle. However, it was also observed that initiatives and resources are being allocated by the companies to address this. This, in turn, allows practitioners to allocate time to test and use new design methods, and it was occasionally observed as incentivizing to practitioners which has positive effects on Category F.
F26: Sustainability-relevant information and data need to be captured	It was frequently observed that sustainability-relevant data need to be captured, either due to upcoming legislation and/or company-specific needs related to corporate targets and visions. Furthermore, this was observed to incentivize practitioners to use design methods when combined with barrier F50 ("do not know what or how to capture") and enabler F51("supports to convey what sustainability relevant information and data to capture"). In turn, this becomes an enabler to the center circle.
F27: Requires collaboration with new internal and external actors	It was frequently observed that new sustainable design practices require practitioners' to collaborate with new actors both internally (e.g., actors from procurement or production, and different specialists) and externally (e.g., new suppliers, and actors enabling circular activities). This will enforce changes in how practitioners currently work and thus become a barrier towards the center circle.
F28: Method applicability limited without understanding	It was frequently observed that when a method expert lacked understanding of company case and context the applicability of the method was low. Lack of understanding will either limit the ability to adapt the design method such that it becomes applicable, or worse, result in an inability to understand if the design method is relevant to their specific challenge or 'problem'. This becomes a barrier towards the center circle and is also amplified by barrier F33 ("difficult to get full understanding"). It does however become reduced by enabler F34 ("practitioners' engagement provides understanding") which supports method experts to adapt the design method and increase applicability.
F29: Eases if company case and context is understood	It was frequently observed that understanding of company case and context supported both understanding if the design method has the potential to fit, but also how to adapt the design method such that it fits the current design process. In turn, this becomes an enabler towards the center circle.
F30: Understanding enables appropriate simplification	It was frequently observed that understanding of company case and context supported reducing the scope of the design methods (i.e., simplifying) such that the minimum accepted boundary conditions are covered when using the design methods. This influences the barrier F11 ("sustainability is considered complex and needs to be simplified") which ensures that misuse is avoided and thus becomes an enabler towards the center circle.
F31: Method experts' interfere when practitioner fails to understand	Some design methods were either applied in a workshop format with a method expert as a facilitator or in a format without the support of a facilitator. In the first scenario, which was more common than the second, method experts frequently interfered with practitioners to clarify 'why and how' to use the design method. In the second scenario, method experts instead supported by assessing the design method outcomes and occasionally had to adjust the design method outcomes. This supported in reducing the risk of design method outcomes that had a reduced and/or negative impact on the sustainability performance of a solution and thus becomes an enabler towards the center circle.
F32: Limited understanding can make integration difficult	It was frequently observed that method experts' understanding of case and context is important when integrating several design methods. Understanding is crucial when adapting design methods such that they can be used in sequence and/or integrate results into other design methods. This is required when the output of one design method is used as input to another, similar to fitting design methods into current design processes. This does for example involve considerations of design method scope, the representation of information and data that is required. This does not act as a barrier towards the center circle, but as a barrier towards factors F38-F42 and reduces their enabling effects on the center circle.

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Table 5 (*continued*)

Factor	Occurrence and degree of influence (see also Fig. 2)
F33: Difficult to get full understanding	It was frequently observed that it is difficult for method experts to get a full understanding of the company case and context. The companies studied are large organizations with hundreds of employees, that all have different roles, internal processes, daily routines, along with complex products. This makes it difficult to get a full understanding of all relevant information and knowledge needed to manage barriers such as F7 ("need to understand how practitioners currently work"), F10 ("adaptation is required"), along with enabler F30 ("understanding enables appropriate understanding").
F34: Practitioners' engagement provides understanding	It was frequently observed that practitioners provide direct input that supports method experts to better understand how to adapt design methods such that they become relevant for the specific challenge or 'problem' and applicable to the specific context. Examples of this are when practitioners described their challenges or 'problems' in detail and asked for desired design method outcomes. Furthermore, it was also frequently observed that practitioners provided method developers with input on the company case and context. Examples of this are drawings, functional descriptions, internal process flows, and available resources. This increased the method experts' understanding, such that they could adapt the design methods accordingly. In turn, this becomes an enabler towards the center circle.
F35: Practitioners have limited time	It was constantly observed that practitioners had limited time available to use design methods. Furthermore, it was frequently expressed and observed that they have limited time. Almost every meeting started with a practitioner either excusing themselves for not having been able to put down the time required for a certain task and/or saying that 'it is stressful at the moment because there is so much going on in our company'. This is both a direct barrier towards the center circle but also amplifies several other barriers that, in turn, also act as barriers towards the center circle.
F36: Practitioners ask for new methods that supports them	It was frequently expressed by practitioners explicitly that they need new design methods that support them in challenges or 'problems' related to sustainable design practices. However, because of many other identified barriers, this factor alone is not enough to satisfy the center circle but becomes an indirect enabler towards the center circle.
F37: Practitioner engagement is limited to AS IS	It was constantly observed that practitioners engage in design methods with the mindset of 'AS IS'. There was a reluctance to change according to what the design method prescribed along with its outcomes. Practitioners constantly brought up the current design practices and clearly stated that design methods cannot affect how the practitioners' currently work. This resulted in design method outcomes that had either a reduced and/or negative impact on the sustainability performance of a solution.
F38: Methods address different sustainable design challenges or 'problems'	It was frequently observed that different design methods address different challenges or 'problems' related to sustainable design practices which incentivize practitioners to use different design methods for different challenges or 'problems'. In turn, this had an enabling effect on barrier F23 ("several design methods are needed") and thus acted as an enabler towards the center circle.
F39: Methods can have synergies with existing methods	It was occasionally observed that the new design methods were possible to integrate with design methods in the existing design processes while also resulting in synergies. There were no observations of how design method outcomes eventually were used in existing design methods due to the period of the study, but practitioner excitement was observed when potential synergies were identified. This can potentially act as an enabler towards the center circle.
F40: Can integrate sustainability in other methods	It was occasionally observed that the new design methods were possible to integrate with design methods in the existing design processes while also integrating sustainability into these. There were no observations of how sustainability eventually was integrated into existing design methods due to the period of the study, but the potential was occasionally observed. In turn, this can act as an enabler towards the center circle.
F41: Methods applied in conjunction can generate a larger knowledge base	It was frequently observed that applying design methods in conjunction i.e., using the design method outcome from one design method into another, supported in the knowledge generated by the design method outcome of that design method. In turn, this acts as an enabler towards the center circle.
F42: Synergies can increase the incentive to adopt	It was frequently observed that integrating design methods increased the incentive to adopt design methods. Having a prescribed logic of how design method outcomes can be built upon and integrated into another design method was explicitly desired by practitioners, as it helps to clarify when and how the design methods should be connected. In addition to this, combining design methods and creating synergies supported addressing a wider range of challenges or 'problems' related to sustainable design practices and was also claimed to be desired. In turn, this incentivized practitioners to adopt design methods.
F43: Requires lot of coordination since many actors need to be involved	It was frequently observed that integrating design methods and using several in conjunction required coordination between several actors. This required detailed planning and coordination, which was time-consuming and non-straightforward. This is not a barrier towards the center circle but reduces the possible enabling effect of design method synergies.
F44: Limited when there is lack of appropriate data	It was frequently observed that the data and information required carrying out the design methods are lacking in the companies. This either reduced the applicability of the design method, led to assumptions, limitations, and/or reduced the scope of the design method. This results in design method outcomes that have a reduced or negative impact on the sustainability performance of a solution.
F45: The information captured needs to be understood	It was frequently observed that the information captured in sustainable design practices needs to be understood. It was occasionally observed that the information was not well understood. Furthermore, it was occasionally also explicitly stated by practitioners that sustainability-relevant information is understood differently both inside the company and by external factors such as suppliers. This can, in turn, result in reduced and/or negative design method outcomes that impact the sustainability performance of a solution.
F46: Information from preceding activities need to be captured	It was constantly observed that information generated from preceding activities in the current design process and/or new design methods need to be captured, such that it can be used as input in the succeeding design method. This is however influenced by barrier F50 ("do not know what or how to capture"). Thus, acts as a barrier towards design methods' fit into the current design process, which in turn becomes a barrier towards the center circle

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Table 5 (*continued*)

Factor	Occurrence and degree of influence (see also Fig. 2)
F47: Information from preceding activities need to be captured	It was frequently reported that information generated from preceding activities in the current and/or new design methods need to be captured, such that it can be used as input in the succeeding design method. This is however influenced by barrier F50 ("do not know what or how to capture"). Thus, acts as a barrier towards integrating design methods and obtaining synergies, which in turn reduces the enabling effect on the center circle.
F48: How methods were used need to be captured	It was frequently observed that 'how the design method was used' was relevant to capture. Mainly since this has positive second-order effects on the center circle, capturing 'how the design method was used' supported in either highlighting and/or preventing misuse of the design method. In turn, this becomes an enabler towards the center circle.
F49: Who were part of the creating the results need to be captured	It was frequently observed that those who were involved in the design method used are relevant to capture. Capturing who was involved can both ensure that the 'right' people and competence take part in the design method and increase traceability. In turn, this acts as an indirect enabler towards the center circle.
F50: Do not know what or how to capture	It was frequently observed that it is not clear what sustainability-relevant information and data need to be captured. Nor is it clear how that data will be retrieved and stored. In turn, this affects the information used as input to design methods along with its representation and has a direct impact on the center circle.
F51: Design methods transfer understanding of 'how and what' sustainability relevant information and data to capture to practitioners	It was frequently observed that adopting new and improved design methods supported clarifying what information and data need to be captured in *sustainable design practices*. In turn, this can have several enabling effects on Category H and thus also the adoption of *sustainable design practices*.
F52: Design methods transfer '*design know-what*' to practitioners	It was constantly observed that adopting new and improved design methods transfers '*design know-what*' to practitioners. It more specifically increased their awareness and understanding, i.e., knowledge, of what change of and/or new design practices are needed to transform to *sustainable design practices*. It highlighted what sustainability-related 'problems' need to be addressed and/or what knowledge is relevant to produce, which in turn can be used to increase the sustainability performance of their solutions. Practitioners had their presumptions about what sustainable design or *sustainable design practices* imply or mean, and what 'problems', or knowledge is relevant to their company. Adopting the design methods challenged these presumptions and supported them in clarifying what knowledge is relevant, and what sustainability-related 'problems' need to be solved. It was occasionally observed as also transferring the ownership of these 'problems' to the practitioners. Furthermore, the practitioners themselves also frequently claimed to obtain increased awareness and understanding of what change of design practice is needed by adopting the design methods. In turn, this can have several enabling effects on Category D and thus also the adoption of *sustainable design practices*.
F53: Design methods transfer '*design know-how*' to practitioners	It was constantly observed that adopting new and improved design methods transfers '*design know-how*' to practitioners. It more specifically increased their awareness and understanding i.e., knowledge, of how their current design practices can be changed, and ideally should be changed. It highlighted how to solve their sustainability-related 'problems' and/or how to produce relevant knowledge, which in turn can be used to increase the sustainability performance of their solutions. It was constantly observed that this supported practitioners in better understanding of what actions and by whom are required to reach specific outcomes, i.e., how to adopt *sustainable design practices*. In turn, this can have several enabling effects on Category F and thus also the adoption of *sustainable design practices*.

3.6. Comparing the proposed descriptive framework with interdisciplinary literature

The proposed framework was lastly compared to interdisciplinary literature to understand how the findings relate to existing theories (Charmaz, 1996), as visualized in Fig. 1. This activity added further nuance and depth to the empirical findings where literature in both the design, and management domain was identified using a snowballing approach (Wohlin, 2014). The focus was to identify literature that can be used to further explain and clarify the empirical findings to bridge these domains and frame the industrial adoption of design methods from all three perspectives (i.e., process and methodology, organization, and human behavior). This, in turn, resulted in a set of what we refer to as **systemic barriers** and **propositions,** which aim to make the empirical findings more easily managed and absorbed. The **systemic barriers** are of a systemic nature that summarizes and highlights key barriers. The **propositions** are instead our proposed means, or suggested action, for addressing these **systemic barriers** based on the findings in our study. These aim to guide both research and practice on what actions and pressing issues need to be addressed to enable the adoption of *sustainable design practices*.

4. Results

The results from the Glaserian grounded theory analysis are divided into two parts. Section 4.1 presents the resulting descriptive framework consisting of 53 interdisciplinary factors that influence the adoption of sustainable design practices using new and improved design methods. Section 4.2 highlights three enabling factors that were captured by the framework, which can expand and nuance the role of new and improved design methods. Furthermore, the empirical findings are further elaborated upon in Section 4.3 where two new concepts are introduced and conceptualized.

4.1. The descriptive framework capturing 53 factors influencing the adoption of sustainable design practices using new and improved design methods

The descriptive framework captures 53 different and interdependent factors that influence the adoption of *sustainable design practices* using design methods. These factors relate to the eight identified core categories and are further described below.

- Category A relates to practitioners' understanding of 'why and how' to appropriately use the design methods proposed by *method experts* and/or *developers*.
- Category B relates to *method developers*' understanding of practitioner needs along with if and how they are translated into the design and development of the new design methods.
- Category C relates to the development of the design methods along with if and how they fit into a company's current design process.
- Category D relates to the nature and characteristics of new *sustainable design practices* along with if and how that, in turn, influences the

practitioners, and the new design methods proposed by *method experts* and/or *developers*.

- Category E relates to *method experts*' understanding of the company case and context along with if and how the new design methods are appropriate and applicable.
- Category F relates to practitioners' engagement and how that influences the use of the new design methods proposed by *method experts* and/or *developers*.
- Category G relates to if and how the new design methods proposed by *method experts* and/or *developers* can achieve synergies and integration with other existing and/or new design methods.
- Category H relates to the information and data in *sustainable design practices* along with how that, in turn, influences the practitioners and the new design methods proposed by *method experts* and/or *developers*.

A summary of all the 53 factors is provided in Table 5, which also indicates each factor's occurrence and degree of influence. The table is best understood together with Fig. 2.

One of the main discoveries among the findings were the identified factors' interdependencies and interdisciplinary nature. The interdependent nature of the framework is further visualized in Fig. 2 where a network diagram is used to highlight the network of factors. The factors are either acting as barriers or enablers, depicted as directed arrows towards the blue center circle, or another core category, depending on the influence (i.e., direct, or indirect). The identified core categories A-H are displayed as yellow boxes. All positive influences, i.e., the enablers, are blue with a plus sign next to the arrow. All negative influences, i.e., the barriers, are red with a minus sign next to the arrow. Several of the factors are similar in nature and phrasing, but each factor results in a unique relation and is therefore also treated as a unique factor. Moreover, the framework also captures and displays factors that indirectly influence the center circle, which occurs when there are factors between categories that, in turn, result in a second and/or third-order effect. For example, F2 ("lack of understanding limits practitioner engagement") is a barrier from Category A to Category F, and it was frequently observed that a lack of understanding of 'why and how' to use methods resulted in decreased engagement by the practitioners. This example highlights the complexity captured by the framework since F2 has negative second-order effects on F34 ("Practitioners' engagement provides understanding"), an enabler to Category E. In turn, this becomes a barrier to Category G via barrier F32 ("Limited understanding can make integration difficult"). Moreover, Category F is influenced by F20 ("Design methods require practitioners' engagement") which in combination with F2 becomes a barrier to adoption. A full and detailed analysis of all the factors is provided as supplementary information. The most significant parts of the framework will, however, be further highlighted in the coming sub-section. Additionally, Section 5 highlights the interdisciplinary nature of the framework while clarifying the practical and theoretical implications of our findings.

4.2. The enabling effects of new and improved design methods

The analysis identified three main enablers that can clarify and nuance what role design methods can have in supporting practitioners in their organization's *sustainability transformation*. The subsections below complement the descriptions of factors 51, 52, and 53 in Table 5 with examples and a more detailed description.

4.2.1. Factor 51 – design methods transfer understanding of 'how and what' sustainability relevant information and data to capture to practitioners

This factor is a direct enabler of Category H ("Information and data capturing in sustainable product development"). It was frequently observed that adopting new and improved design methods supported clarifying what data needs to be captured in *sustainable design practices*. Design methods have a prescribed input along with how information and data should be represented, this was observed as supporting practitioners to create a common language and representation of sustainability information and data. One practitioner did, for example, state that the design methods "provide a common language and shared understanding of sustainability" as well as "terminology around sustainability". Furthermore, the design methods also prescribe what sustainability information and data is needed to appropriately use the design methods, i.e., relevant sustainability data. This clarified what information and data is necessary to retrieve and store both from internal functions and external stakeholders, such as suppliers. One practitioner did for example state that "the method resulted in a way to express component requirements to suppliers". Another practitioner stated that "earlier, procurement did not have the right knowledge about sustainability to be able to make decisions (related to suppliers)". In turn, this can have several enabling effects on Category H and thus also the adoption of *sustainable design practices*.

4.2.2. Factor 52 – design methods transfer 'design know-what' to practitioners

This factor is a direct enabler of Category D ("New *sustainable design practices*"). It was constantly observed that adopting new and improved design methods transfers '*design know-what*' to practitioners. It more specifically increased their awareness and understanding, i.e., knowledge, of what change of and/or new design practices are needed to transform to *sustainable design practices*. It highlighted what sustainability-related 'problems' need to be addressed and/or what knowledge is relevant to produce that, in turn, can be used to increase the sustainability performance of their solutions. Practitioners had their presumptions about what sustainable design or *sustainable design practices* imply or mean, and what 'problems', or knowledge is relevant to their company. Adopting the design methods challenged these presumptions and supported them in clarifying what knowledge is relevant, and what sustainability-related 'problems' need to be solved. It was occasionally observed as also transferring the ownership of these 'problems' to the practitioners. One practitioner did for example state that the main purpose of the design methods is to "ask the right questions", i.e., what 'problems' to solve or knowledge to produce. Furthermore, the practitioners themselves also frequently claimed to obtain increased awareness and understanding of what change of design practice is needed by adopting the design methods. One practitioner did, for example, state that "I have learned so much more, I thought I already knew a lot". Another practitioner stated that "it supports creating increased awareness". It was also stated that it supported "shedding light" on sustainability. In turn, this can have several enabling effects on Category D and thus also the adoption of *sustainable design practices*.

4.2.3. Factor 53 – design methods transfer 'design know-how' to practitioners

This factor is a direct enabler of Category F ("Practitioners' design method engagement"). It was constantly observed that adopting new and improved design methods transfers '*design know-how*' to practitioners. It more specifically increased their awareness and understanding i.e., knowledge, of how their current design practices can be changed, and ideally should be changed. It highlighted how to solve their sustainability-related 'problems' and/or how to produce relevant knowledge that, in turn, can be used to increase the sustainability performance of their solutions. The design methods prescribe who needs to be involved and how they should be involved in the design methods. Furthermore, the design methods also prescribed a structured approach for what questions need to be answered as well as what actions and inputs are needed to reach specific outcomes, i.e., how to produce knowledge or how to solve a 'problem'. It was constantly observed that this supported practitioners in better understanding of what actions and by whom are required to reach specific outcomes, i.e., how to adopt *sustainable design practices*. One practitioner did for example state that the design methods support in a "structured way of how we can achieve

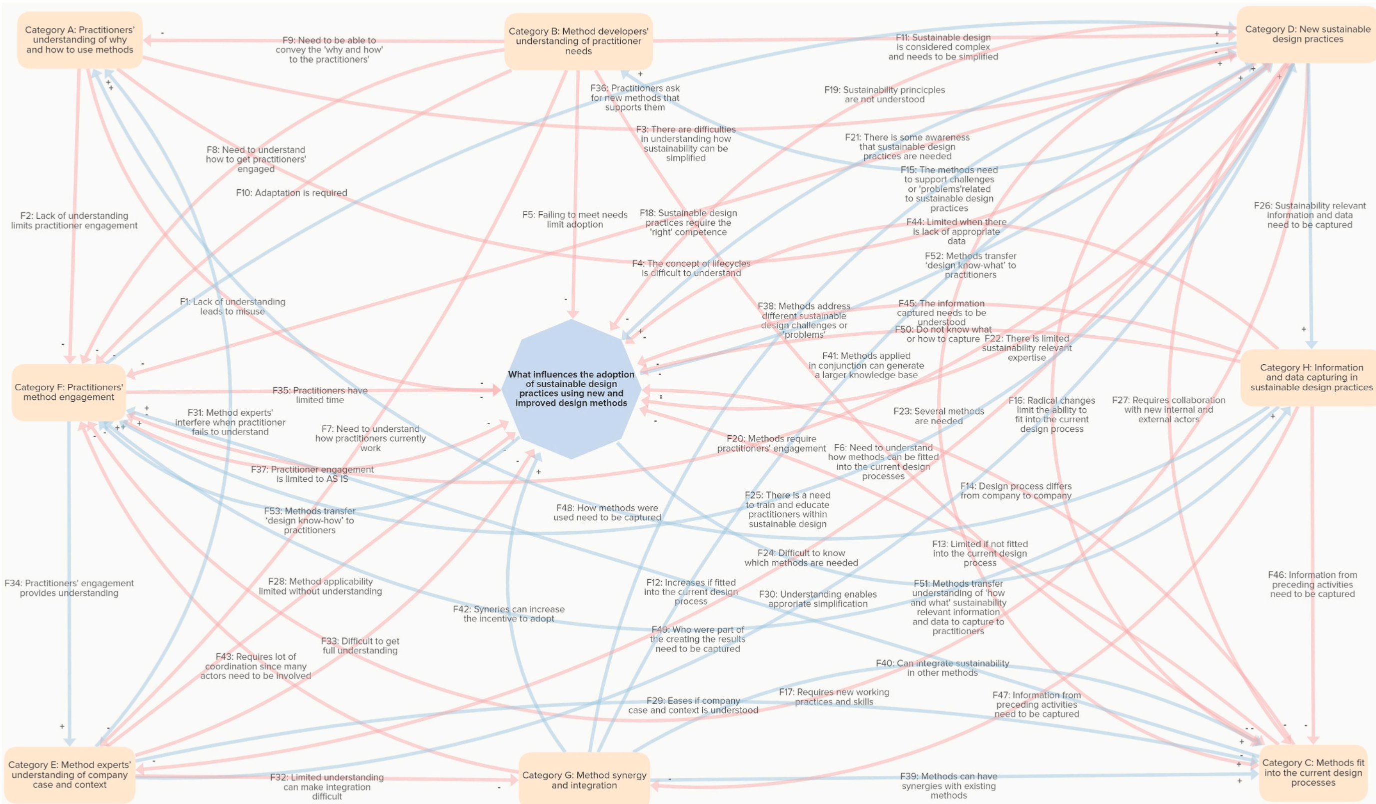

Fig. 2. The final descriptive framework.

the sustainability goals – where to start and then which actions to take". Another practitioner stated that it "provides a structured way of integrating sustainability". In turn, this can have several enabling effects on Category F and thus also the adoption of *sustainable design practices*.

4.3. Conceptualizing the nature of design methods

The literature provided in Section 2.3 was not considered sufficient to explain and clarify several of the identified factors and bridge the three perspectives. Two new concepts referred to as the *situational design problem* and the *dualism of design methods* are therefore proposed and further conceptualized in this section and used in Section 5 to facilitate the discussion.

4.3.1. Introducing the situational design problems of practitioners

From a practitioner's point of view, design methods support solving what was referred to as 'problems' as observed in factors 52 and 53. These 'problems' are situational problems or challenges, and occasionally explicit and unmet needs that arise in the design process when current design practices, or design methods, are considered insufficient. Furthermore, these observed 'problems' are divided into three types or layers: (i) The *Situational design problem*; (ii) *Situational sub-problems*; and (iii) *Contextual problems*. Type one (*situational design problem*) relates to the core of such 'problems' and is typically how problems in the empirical study were and would be, formulated by a practitioner. Examples of such *situational design problems*, or unmet practitioner needs, that arose in the empirical study were:

- How to understand the feasibility and system effects of changing materials?
- How to assess and realize lifecycle strategies?
- How to capture and define contextually relevant sustainability criteria?
- Need to formulate criteria that can be used in collaboration processes.
- How to assess risks related to long-term sustainability compliance?
- Need a shared understanding of what sustainability means.
- How to identify sustainable materials?
- Need to be able to identify the value of different design strategies.

These *situational design problems* typically relate to the need, or current challenge, of generating different sets of knowledge considered relevant to the *design problem*, and this study focused on sets of knowledge required to develop more sustainable solutions. However, to clarify, satisfying such a need or solving a *situational design problem* by e.g., adopting a new and improved design method does not solve the original *design problem* as such. Type two (*situational sub-problems*) were, and would, typically not be stated explicitly by practitioners but are instead sub-problems that have been identified as necessary to solve by e.g., the *method developer* during the development of the design method. Design methods proposed by e.g., design researchers, are ideally rigorously developed, tested, and sufficiently mature when proposed to practitioners. *Situational sub-problems* can for example relate to how to structure and represent information in a condensed format such that it can be communicated internally to make the design method user friendly, or how to systematically divide sustainability criteria according to lifecycle phases which might result in a sub-step in the design method. Type three (*contextual problems*) is important to distinguish from types one and two since these refer to 'problems' that either differ from organization to organization, or from case to case and are thus contextual. Examples of *contextual problems* from the empirical study were requests to adapt the design methods to company language, or what some practitioners referred to as making them "companyfied" and thus differ from organization to organization. Another *contextual problem* instead related to the need to efficiently link the design methods, or rather their accompanied computer tools, to the organization's internal information and data management system. Such systems also differed from organization to organization and became a *contextual problem*. In many instances, *contextual problems* are generally related to explicit requests to simplify, adjust, and/or modify the design methods to better align with their organizational context (e.g., product, internal processes, and resources), or *method ecosystem*.

4.3.2. Introducing the dualism of design methods

The *dualism of design methods* builds on the finding that factors 52 and 53, where design methods were observed to transfer both '*design know-what*' and '*design know-how*' to practitioners. The *Design know-what* encapsulates and transfers knowledge of what *situational design problems*, *situational sub-problems*, and occasionally *contextual problems*, are relevant to practitioners. The *Design know-how* instead encapsulates and transfers knowledge of how practitioners can solve specific *situational design problems*, *situational sub-problems*, and occasionally *contextual problems*. This also indicates that design methods are constituted by two halves, or a dualism, and is further illustrated in Fig. 3. We use the Double Diamond (Design Council, 2005) for pedagogic reasons to highlight this dual nature and frame design methods as designed artifacts (i.e., designs). The *Design know-what* is portrayed as and relates to the 'problem space' and the *Design know-how* to the 'solution space' respectively. As mentioned, the *Design Research Methodology* (Blessing and Chakrabarti, 2009) is a commonly used research methodology, or 'design process', for developing design methods, and the generic steps of this process are therefore fitted accordingly to clarify this reasoning.

The *dualism of design methods* also supports highlighting that design methods are value-laden artifacts, or designs i.e., design methods are a means to an end, where the end is value-laden. Furthermore, design methods pursue different goals aiming to improve the design process (Blessing and Chakrabarti, 2009) by solving or addressing different *situational design problems*. Furthermore, the *dualism of design methods* highlights and nuances the role of design methods, they can be used to convey and/or transfer:

(i) How to solve *situational design problems* relevant to the *design problem*.
(ii) What *situational design problems* are relevant to the *design problem*.
(iii) How to produce knowledge relevant to the *design problem*.
(iv) What knowledge about the *design problem* is relevant to produce.

5. Discussion

The descriptive framework captures and highlights what factors influence the adoption of sustainable design practices using new and improved design methods. However, the mechanisms behind the factors as well as how they should be addressed need to be further discussed and compared to previous research. Furthermore, this enables us to summarize and categorize the 53 influencing factors as nine **systemic barriers** and eight **propositions**, which in turn further highlight and clarify the theoretical and practical implications of our findings.

5.1. Facilitating the adoption of new and improved design methods

Literature in the design domain has mainly treated design methods as prescriptive means for transferring a type of 'know-how' about designing (see e.g., Eder, 1998; Wallace, 2011; Daalhuizen and Cash, 2021; Gericke et al., 2022) and align with what we proposed as the *Design know-how*. Furthermore, we also claim that design methods can, and should, be considered as 'designs' that solve *situational design problems*. Moreover, in our proposed concept we also introduce the *Design know-what* which is less elaborated upon in the design domain. There are similar concepts, such as *method goal* (Daalhuizen and Cash, 2021) and *intended use* (Gericke et al., 2022), but these are not framed nor discussed as potential barriers to adoption. We instead use the *Design know-what* to explicitly highlight design methods as being value-laden artifacts, i.e., not only a means to an end but also an end. Our proposed concept provides a nuanced view of design methods and will be used to describe and explain several of the barriers and enablers captured in the descriptive framework. It is possible to formulate five **systemic barriers** and three **propositions** which are elaborated upon in the coming subsections.

5.1.1. The situational design problem paradox

The nature of a *situational design problem* shares similar characteristics to *design problems* i.e., they are also ill-structured, ill-defined, to some extent wicked, and unique (Rittel and Webber, 1973; Archer, 1979; Buchanan, 1992; Simon, 1969; Dorst, 2006; Gericke et al., 2022), see e.g., F10 ("adaptation is required"), and F14 ("the design process differs from company to company"). A paradox, referred to as the *situational design problem paradox* is therefore introduced here. This paradox claims that design methods, in theory, are limited in their transferability, or applicability, since *situational design problems* are thus also unique. Such a paradox, in turn, indicates that the use and applicability of proposed design methods are limited since the *situational design problem* will differ every time. This claim indicates that previously proposed and used design methods are never applicable again. However, such a claim has partly been proven false since many design methods have been proven useful in several different and unique design situations such as *Quality Function Deployment* (see e.g., Chan and Wu, 2002), or *Business Model Generation* (Osterwalder and Pigneur, 2010) also referred to as *Business Model Canvas* in the context of business design. The *situational design problem paradox* is, however, still a barrier but needs to be better understood. First, the influence of this paradox depends on how relevant and/or 'common' the *situational design problem*, i.e., its *Design know-what*, is to practitioners, and if the design methods are externally valid (Säfsten and Gustavsson, 2020). It was observed in the empirical study that this varied among the different design methods proposed, see e.g., F7 ("need to understand how practitioners currently work") or F24 ("difficult to know which design methods are needed"), and influenced adoption since the design methods need to address a *situational design problem* relevant to the practitioners. This entails **Systemic barrier 1a:**

> The *situational design problem paradox* limits a design method's transferability and applicability to practitioners.

Second, *situational design problems* are seemingly unique since modifications and adaptations to the design methods were frequently required in the empirical study, see e.g., F11 ("sustainability is considered complex and needs to be simplified") and F10 ("adaptation is required"). Most of the requests were related to what we refer to as *contextual problems* and these rarely influenced the outcomes. The requests did, however, occasionally require significant modifications to what we refer to as *situational sub-problems* and such modifications influenced the outcomes to a larger extent. Such modification and adaptation were not straight-forward and required the facilitation of what we refer to as a *method expert*, mainly due to F3 ("there are difficulties in understanding how sustainability can be simplified") and F22 ("there is limited sustainability relevant expertise"), and F30 ("understanding enables appropriate simplification"). The design researchers, here acting as *method experts*, had to study the case company and context in detail to make appropriate modifications and contextualization to not influence the design method outcome negatively, see Category E ("*Method experts*' understanding of company case and context"). This activity was recognized as highly important and appreciated by practitioners, see e.g., F12 ("increases if fitted into the current design process"). Literature has also

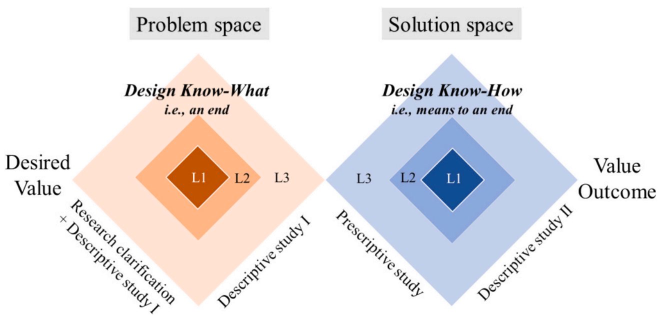

Fig. 3. Depicting *the dualism of design methods*. Each space is further divided into the *Situational design problem* (L1), *Situational sub-problems* (L2), and *Contextual problems* (L3).

highlighted the need for adaptation and contextualization. Eder (1998) did for example state "the method must be adapted to problem and situation, adapted to different kinds of product and peculiarities of the enterprise" while highlighting the importance of individuals in an organization that can carry out such adaptation. Wallace (2011) also highlighted the need for contextual adaptation when stating that a crucial barrier to adoption is when design methods do not fit practitioners' working practices. Gericke et al. (2020) refer to this context as the *method ecosystem* where design methods need to fit and typically require adaptation. Gericke et al. (2021) also stated that such context is "fuzzy", claiming that contextual adaptation is one of the reasons for low industrial uptake. We argue that adopting a design method is rarely, or ever, a 'plug-and-play' and requires consideration and facilitation when introduced in new contexts. Furthermore, contextual adaptation of design methods also requires an extensive understanding of the company, case, and context, i.e., domain-specific competence, and highlights the need for *method experts* who can be responsible for such contextual adaptation. This entails **Systemic barrier 1b:**

> The *situational design problem paradox* requires a design method to be modified and contextually adapted to be applicable and accepted by practitioners, which is a time-consuming activity requiring *method experts*.

The above findings provide empirical evidence that *situational design problems* are similar to *design problems* since they also appear to be ill-structured, ill-defined, to some extent wicked, and unique. It is, however, beneficial to distinguish what type of problem hinders adoption, i.e., if it relates to the *situational design problem*, *situational sub-problems*, or *contextual problems*. Different activities and resources are required, and suitable, depending on which type of problem needs to be addressed. For example, mature and user-friendly computer tools have been highlighted as important for acceptance and adoption in this empirical study and literature (see e.g., Thia et al., 2005; López-Mesa and Bylund, 2011; Gericke et al., 2020). Araujo et al. (1996) even found that practitioners perceived the utility of a design method improved if it was implemented using a computer. This, on the one hand, emphasizes the need for maturing design methods and developing user-friendly tools as it is important for efficient scaling and increasing the potential use inside an organization. However, the empirical study also highlighted that developing such a 'mature enough' and user-friendly computer tool requires *contextual problems* to be addressed. This is both time-consuming and requires a detailed understanding of the organization, and occasionally requires competencies and resources beyond what a *method developer* possesses. Wallace (2011) did for example claim that "it is not the main task of academic researchers to write software code, even if they are competent at it … the resulting software is not likely to be sophisticated, robust or user-friendly by modern standards". We, therefore, argue that some problems hindering adoption are better addressed by e.g., *method experts*, and occasionally require support from the organizations seeking to adopt the design method. Furthermore, design methods are commonly requested to be modified and adapted, or 'improved', to fit an organization's current design practices and the needs of practitioners. We do, however, argue that it is not always and necessarily the design method, i.e., the *Design know-how*, that is the reason for limited adoption. It is important to understand what *situational design problem* the design method intends to solve i.e., the *Design know-what*, since it can be the main reason for low applicability. This entails **Proposition 1a:**

> *Method experts* and/or *developers* and practitioners need to understand the barriers towards adoption in regards to the *situational design problem*, *situational sub-problems*, and *contextual problems*, such that resources are allocated effectively.

5.1.2. The dualism of design methods paradox

It became evident in the descriptive framework that there is an initial hesitation or skepticism towards adopting new and improved design methods, and there is a clear preference to keep practices to what we refer to *AS IS*, see e.g., F37 ("practitioner engagement limited to AS IS"). Practitioners also frequently stressed the need to understand why new and improved design methods are needed, see factors related to Category A ("Practitioners' understanding of 'why and how' to appropriately use design methods"). Several practitioners were hesitant to adopt new design methods before their first use but did however perceive their relevance after the design methods had been tested and used, which becomes a 'chicken or the egg' dilemma. The design methods did address relevant *situational design problems*, but the practitioners did not consider the *situational design problems* relevant before using or testing the design methods. This introduces the *dualism of design methods paradox* which claims that the *Design know-what* must be intrinsically adopted before the *Design know-how* can be adopted, but the *Design know-what* can only be intrinsically adopted by using the design method, i.e., adopting the *Design know-how*. This is also why we argue that it is important to consider and understand design methods as value-laden artifacts, i.e., not only a means to an end but also an end, which practitioners must intrinsically possess. To clarify, when we propose new and improved design methods to practitioners, we assume either and/or that the practitioner wants: (a) the *situational design problem* to be solved; and/or (b) to produce that knowledge about the *design problem*. And they usually do want (a) and/or (b) but the challenge is that they do not know it, 'yet'. This entails **Systemic barrier 1c:**

> The *Design know-what* must be transferred before the need for the *Design know-how* is perceived, but the *Design know-what* is seldom adopted before adopting the *Design know-how* which introduces the *dualism of design methods paradox*.

A similar issue was also reported by Araujo et al. (1996) who conducted a large quantitative study with companies in the United Kingdom and concluded that "many companies are unaware of the potential quality benefits of available methods". This issue and paradox pose a real challenge to adoption, but our empirical study did, however, indicate via factors 52 and 53 that the *situational design problem*, or 'value', of the design method can be transferred when design methods are adopted (i.e., used). Furthermore, López-Mesa and Bylund (2011) also claimed that "the value is only understood when you have some practical experience with it" which supports our paradox and our claim that design methods can transfer the *situational design problem* they intend to solve. This entails **Proposition 1b:**

> The *Design know-what* needs to be fully understood or tested before deeming the design method to be of no relevance to the practitioner and their *design problem*. Adopting new and improved design methods can transfer what *situational design problems* and what set of knowledge are relevant to their *design problem*.

"We all love to instruct, though we can teach only what is not worth knowing" – Jane Austen in *Pride and Prejudice* (1813, chapter 4)

5.1.3. The prescriptive nature of design methods

'Change' is in general acknowledged as a challenging social phenomenon and it is clear how it influences the adoption of new and improved design methods since it will naturally require process and methodological change. López-Mesa and Bylund (2011) are one of few in the design domain who acknowledge that "people do not want to change their way of working" while briefly referring to Kotter (1995). Similar was highlighted by Jagtap et al. (2014) who also referred to Kotter (1995), but this did not gain any significant traction in the design domain. It is important to acknowledge change which results in **Systemic barrier 1d:**

> Adopting new and improved design methods induces process and methodological change which is a well-studied social phenomenon and acts as a natural barrier to adoption.

Design methods are in their nature a prescription of how a *situational design problem* should be solved and, in turn, affect the autonomy of practitioners since it limits their ability to influence how they design. *Autonomy* is a critical element in achieving social acceptance and motivation (Hackman and Oldham, 1976; Deci et al., 2017) and thus requires attention. Furthermore, López-Mesa and Bylund (2011) also found that practitioners believe that "methods reduce freedom to think and are boring" but did not specifically refer to autonomy. The role of autonomy is important to highlight and acknowledge since it can provide further clarification of why there is an instant hesitation to adoption and why practitioners frequently want to be involved in modifying and adapting the design methods, see Section 2.4 or Hackman and Oldham (1976). This entails **Systemic barrier 1e:**

> The nature of adopting prescriptive design methods points to reduced autonomy which is a key element in work design and more specifically the *Self-Determination Theory*.

Factor 52, or the *Design know-what*, was observed to convey what change is required and we propose it be utilized to facilitate change and social acceptance. The *Design know-what* is a potential means for transferring increased awareness and understanding and aligns with the first step provided in Kotter's change model, i.e., "establishing a sense of urgency" (Kotter, 1995). Furthermore, design methods, or the *Design know-how* provide a prescription for how to realize this change. However, as evident in sub-sections 5.1.1 and 5.1.2, adoption is challenging and seldom a 'plug-and-play'. It is therefore worth considering whether we want the practitioner to either: (a) solve the *situational design problem* using the design method as it is exactly prescribed; or (b) solve the *situational design problem* that the design method intends to solve. Mainly since (b) is a probable superset to (a) but not vice versa. We argue that (b) is more important than (a) since the design method is one of many ways to solve the *situational design problem* (Rittel and Webber, 1973; Buchanan, 1992). Furthermore, we also argue, due to the contextual nature of designing, that a practitioner is best suited to deem how to modify and use a design method, assuming the practitioner is fully knowledgeable of the *Design know-what*. This entails **Proposition 1c:**

> Design method adoption should be carried out in a cyclic or iterative nature. First-cycle adoption is an initial trial of the *Design know-how* increasing awareness and understanding via the *Design know-what* i.e., what change is needed. Second-cycle adoption focuses on fully adopting the *Design know-what*, either via the *Design know-how* or by modifying and adapting it to better suit the *situational design problem* and its context.

5.2. The adoption of new and improved design methods in the context of a sustainability transformation

Section 5.1 focused on providing a better understanding of why it is natural to encounter challenges when proposing new and improved design methods to practitioners, and how adoption can be facilitated. Section 5.2 instead shifts focus and aims to highlight why product development and manufacturing organizations must face, and can face, these challenges to achieve a *sustainability transformation*. It is possible to formulate four **systemic barriers** and five **propositions** which are elaborated upon in the coming subsections.

5.2.1. Organizational change in the paradigm of sustainable design

The descriptive framework includes several barriers that relate to how design or rather what we introduce here, a *paradigm of product design*, is practiced in industry from a process and methodological perspective. This *paradigm of product design* represents a persisting way of practicing design in product development and manufacturing organizations, which in turn pose significant challenges to practitioners and their organization's *sustainability transformation*, see e.g., F16 ("radical changes limit the ability to fit the current design process"), F27 ("requires collaboration with new internal and external actors"), and factors related to Category D ("New *sustainable design practices*"). The *paradigm of product design* mainly perceives and treats product design as functionality and performance in use (e.g., weight, power), geometry, component, and part integration, along with material selection. Such a *paradigm of product design* can also be found in literature. For example, Cross (2023) also refers to the traditional design as more focused on physical objects, and Ulrich and Eppinger (2016, p3) provide the following description:

> "The design function plays the lead role in defining the physical form of the product to best meet customer needs. In this context, the design function includes engineering design (mechanical, electrical, software, etc.) and industrial design (aesthetics, ergonomics, user interfaces)."

Lee (2021) criticizes current design practices, while referring to the paradigm of *design thinking*, arguing that it still withholds a focus on making physical artifacts despite other claims. We argue that such a narrow view of design results in a limited ability to implement *sustainable design practices* and propose sustainable solutions i.e., incorporating the eight socio-ecological principles throughout the product's full lifecycle. The *paradigm of product design* results in a systemic process and methodological incompatibility since the nature of the new and improved design methods are incompatible with how design, or rather product design, is currently practiced in these organizations. Furthermore, this influenced both the ability and attitude towards adopting the proposed design methods and did in several instances require significant modification, which in turn influenced the method outcomes negatively. Examples relate to the inclusion of social aspects in the full value chain and can pose a risk of preserving social issues such as inequality and health risks during material extraction. There was in general a limited ability to consider the full lifecycle of products, see e.g., F4 ("the concept of lifecycles is difficult to understand") and F19 ("sustainability principles are not well understood"). This means that not only social but also ecological issues can be preserved in downstream and/or upstream activities. Furthermore, Mallalieu et al. (2023) also highlight this issue and provide concrete examples of how sustainability criteria can be incorporated into design space explorations while highlighting the difficulties in integrating less conventional sustainability criteria. Physical aspects are compared to non-physical aspects more easily treated in current design practices. This entails **Systemic barrier 2a:**

> Organizations' current design practices align with the *paradigm of product design* and result in a systemic process and methodological incompatibility with *sustainable design practices*.

Our claim is supported by and elaborated on by other scholars, where Eppinger (2011) for example criticized current "product design practices" (i.e., the *paradigm of product design*) stating that in terms of incorporating sustainability it "remains largely in the dark ages". Pigosso et al. (2013) did not explicitly state the need for systemic changes to current design practices but did for example state that companies must "implement life cycle thinking" to enable the development of more sustainable solutions. Bocken et al. (2014) stated that "these types of changes require a fundamental shift in the purpose of business and almost every aspect of how it is conducted" when discussing strategies to propose more sustainable solutions. Ceschin and Gaziulusoy (2016) also emphasize the need to go from product design to "systemic design". Sumter et al. (2018) also argue that the "role of product design will, and must, expand". Julier and Kimbell (2019) focus on social design, i.e., design aimed at addressing social issues, and they question if current design practices are sufficient to address such complex sustainability-related *design problems*. Hallstedt et al. (2020) elaborate on the future of design and designers accordingly:

> "These trends clearly impact the role of the designers that are expected to design entire solutions as opposed to merely artefacts in the future. This implies that designers need to consider not only the product performance and cost, but also the behavior of products and solutions and their impact over complete life-cycles, developed and organized by business networks together with several suppliers and other partners with different capabilities."

The *paradigm of product design* thus provides a limited scope to design which is not sufficient to produce relevant and required knowledge about the *design problem* to develop and propose sustainable solutions. We, therefore, propose that the design practices in organizations must adapt and change to instead enter a *paradigm of sustainable design*. This entails **Proposition 2a:**

> There is a need for a systemic shift away from the *paradigm of product design* towards the *paradigm of sustainable design* to enable the adoption of *sustainable design practices*.

Several of the identified barriers relate to social acceptance and/or an attitude towards conflicts with current design practices, i.e., the need for change. This explains the explicit requests to modify and adapt proposed design methods to better fit their current design practices, see e.g., F6 ("need to understand how design methods can be fitted into the current design process"), F10 ("adaptation is required"), and F12 ("increases if fitted into the current design process"). Literature in the design domain (see e.g., Eder, 1998; Wallace, 2011; Booker, 2012) also emphasizes the need to modify and adapt design methods to fit into current design practices without referring to managerial literature. Furthermore, Faludi et al. (2020) in the context of *sustainable design practices* also stated that "tools should be easier to apply and compatible with existing business and design methods and processes". Quella and Schmidt (2003) also highlighted the importance of integrating environmental strategies with the current design process along with ensuring "social acceptance". This is according to us a pragmatic and natural mindset or approach which *method experts* and/or *developers* tend to utilize to increase the chances of adoption, i.e., they reduce the need for change since change typically is challenging to achieve (Samuelson and Zeckhauser, 1988; Kotter, 1995). A similar approach is utilized and proposed in several other studies (see e.g., Lindahl, 2006; O'Hare et al., 2010; Faludi et al., 2020; Parolin et al., 2024). However, such a mindset and 'pragmatic approach' can result in stagnation and limited ability to adopt *sustainable design practices* and ability to develop and propose more sustainable solutions. This entails **Systemic barrier 2b:**

> There is a pragmatic mindset in the *paradigm of product design* where the attitude and social acceptance towards process and methodological conflicts, i.e., the need for change, limits the ability to appropriately adopt *sustainable design practices*.

Entering the *paradigm of sustainable design* will instead require a shift of mindset towards the adoption of *sustainable design practices* using new and improved design methods. Transitioning to such a paradigm will result in process and methodological conflicts, i.e., there will be a need for change. We therefore argue that both practitioners, *method experts,* and/or *developers* need to consider the human-behavioral aspects proactively and intentionally to achieve such change. Furthermore, Hackman and Oldham (1976) highlight autonomy and the importance of practitioner involvement when designing work tasks to achieve motivation and social acceptance. Kotter (1995) also urges to involve people in the process of organizational change to gain traction. A similar proposal was made by Faludi et al. (2020) but without referring to managerial literature that explicitly highlights co-creation. Co-creating, or co-evolving current design practices requires a change of mindset by both *method experts* and/or *developers*, and practitioners, and do for example require two-way communication. Potential conflicts and incompatibility can for example serve to highlight where current design practices need to evolve to better align with *sustainable design practices*. Adaptation, modification, or pragmatic requests, by practitioners need to be considered. However, practitioners must at the same time understand that a systemic change is needed to enable a *sustainability transformation*. For example, F44 ("limited when there is lack appropriate data") both poses a barrier but also indicates that there is a need for making such data accessible. Furthermore, testing and using new and improved design methods was also observed to improve current design methods and practices and incorporate sustainability, see e.g., F40 ("can integrate sustainability into other design methods"). This entails **Proposition 2b:**

> The mindset in the *paradigm of sustainable design* requires a change of attitude and increased social acceptance towards process and methodological conflicts, i.e., the need for change, and is seen as an opportunity to improve and co-evolve towards *sustainable design practices*.

5.2.2. Pseudo-sustainability and the need for cognitive bias reduction

Several of the barriers identified in the descriptive framework can be related to insights provided by literature treating *agency theory* (Mitnick, 1992; Eisenhardt, 1989), *institutional theory* (Meyer and Rowan, 1977; DiMaggio and Powell, 1983), and *cognitive barriers* or *biases* (Simon, 1969; Mitnick, 1992). We argue that there is a presence of several different *cognitive biases* that currently influence adoption negatively, see e.g., F3 ("there are difficulties in understanding how sustainability can be simplified"), F4 ("the concept of lifecycles is difficult to understand"), F19 ("sustainability principles are not understood"), F25 ("there is a need to train and educate designers within sustainable design"), and F37 ("practitioner engagement limited to AS IS"). Furthermore, Klotz et al. (2018) studied how different *cognitive biases* can lead to 'sub-optimal sustainability performance' and broadly define *cognitive biases* as "systematic patterns of deviations from classical notions of rationality are called 'cognitive biases', and influence what we view as desirable and possible". Weber (2017) instead discusses cognitive barriers in decision-making and how they result in a "status quo" that limits sustainable development and long-term benefits. The *cognitive biases* in our study mainly arise due to competence and presumptions of sustainable design practices, different self-interests, personal preferences, and/or social norms. The need to use *heuristics* also appears in the descriptive framework, see e.g., F11 ("sustainable design is considered complex and needs to be simplified"). The presence of these *cognitive biases* provides a further explanation for the frequent requests by practitioners to modify, adapt, and occasionally simplify, the proposed design methods to better fit their current design practices, which in turn results in the 'pragmatic approach' utilized in the design domain discussed in Section 5.2.1. Design methods are, as previously highlighted, in many cases treated as insufficient by practitioners and in need of 'improvement' to better fit *AS IS*, or *status quo* due to *cognitive biases*.

However, such a 'pragmatic approach' to account for *cognitive biases* can, in turn, lead to a state of *pseudo-sustainability* i.e., the adoption of instances, or 'cherry-picked' parts, of *sustainable design practices*. *Pseudo-sustainability* is the result of either the intentional, or unintentional, exclusion of any of the eight socio-ecological principles in either of a product's lifecycle phases, which results in *pseudo-sustainable designs*. This entails **Systemic barrier 2c:**

> The presence of *cognitive biases* influences the ability to fully embrace and adopt *sustainable design practices* using new and improved design methods, which in turn leads to a state of *pseudo-sustainability*.

The *dualism of design methods paradox* introduced in Section 5.1.2 is also relevant to discuss here. We there claimed that design methods are value-laden and that a *method expert* and/or *developer* thus make assumptions when proposing a new and improved design method to a practitioner, i.e., that the practitioner wants: (a) the *situational design problem* to be solved; and/or (b) to produce that knowledge about the *design problem*. And that they usually do want (a) and/or (b) but the challenge is that they do not know it, 'yet'. The *cognitive biases* of practitioners i.e., their preferences, self-interests, current competence, and presumptions towards *sustainable design practices*, limit them from currently seeing the need of (a) and/or (b), i.e., practitioners do not intrinsically possess the end of the proposed design methods. This barrier mainly relates to the *Design know-what* and not the *Design know-how* of the proposed design methods. *Cognitive biases* must therefore be systematically challenged in product development and manufacturing organizations since they will continue to influence adoption negatively irrespective of how 'good' or 'mature' proposed new and improved design methods are.

5.2.3. Introducing sustainable design thinking

There has been extensive research about *sustainable design practices* and what remains is thus the actual implementation. Blizzard and Klotz (2012) and Bocken et al. (2014) for example propose generic strategies for how product development and manufacturing organizations can improve. There are also more extensive frameworks focusing on how organizations can mature towards more *sustainable design practices*, see e.g., Ceschin and Gaziulusoy (2019) and Pigosso et al. (2013). There is also a plethora of underutilized design methods (Faludi et al., 2020). Baldassarre et al. (2020) also claimed:

> "However, these theoretical speculations on sustainable design will not go to great lengths, unless they are tied to solid business considerations. Indeed, evidence shows that sustainable design ideas can be implemented successfully only when they are grounded into the objectives and operations of organizations."

For example, practitioners on lower levels have contextual awareness and make operational decisions with tangible impact on the design, or product. There is, however, also a need to understand and practice sustainable design top-down to ensure appropriate managerial support (see e.g., Bey et al., 2013), by e.g., supporting change, defining aligned targets and objectives, as well as allocating resources to enable such practices. This study also indicates that a *sustainability transformation* will be challenging unless we systematically challenge the *cognitive biases* of practitioners at every level of an organization (and potentially society). *Sustainable design* must be understood and practiced on all levels of an organization, or what Eisenhardt (1999) refers to as a *collective intuition* i.e., a common understanding or collective competence. The empirical findings highlight the specific potential of design methods (see factor 52 "design methods transfer '*design know-what*' to practitioners"), to challenge practitioners' *cognitive biases*, e.g., values and norms, which currently hinder the adoption of *sustainable design practices*. Similar potential was also reported by Liedtka (2015) where *Design thinking*, or *designerly ways of knowing, thinking, and acting* (Cross, 2023), was shown to address different kinds of *cognitive biases*. There is thus a need for a supposed *Sustainable design thinking*[2] that every practitioner in a product development and manufacturing organization can practice. This entails **Proposition 2c:**

> The *cognitive biases* of practitioners can be challenged by practicing *Sustainable design thinking* on all levels of an organization.

The proposed concept of *Sustainable design thinking* requires further investigation and development, and the paradigm of *design thinking* (Brown, 2008; Brown and Katz, 2011; Verganti et al., 2021) can serve as a role model in how it has effectively gained traction in different problem-solving practices by transferring the core principles of *design* (Dorst, 2011; Cross, 2023). Furthermore, two key competencies need to be transferred and thus incorporated into *Sustainable design thinking*: (1) *Design competencies*, which refer to the principles of *designerly ways of knowing, thinking, and acting* which for example focus on the *co-evolution of problem-solution* and a better understanding of the *design problem* (see e.g., Cross, 1982; Dorst and Cross, 2001; Dorst, 2011; Cross, 2023). (2) *Sustainable design competencies*, which refer to the principles presented in the *Framework for Strategic Sustainable Development* (Broman and Robèrt, 2017). Moreover, *Sustainable design thinking* is not striving to disregard or substitute the role of e.g., sustainability experts, or designers with specialized knowledge in sustainable design in organizations. It is neither striving to substitute proven frameworks and design methods for sustainable design, such as the design methods used in the empirical study, or previously proposed design methods within *eco-design*, *design for sustainability*, and/or quantitative design methods (e.g., *LCA*). *Sustainable design thinking* mainly aims to develop base competence that can and needs to, be practiced by any *designer,*[3] or *sustainable designer,*[4] in organizations to systematically challenge the *cognitive biases* present in organizations. The *paradigm of sustainable design* can only be entered when *Sustainable design thinking* is collectively understood and accepted in an organization.

> "The transition between competing paradigms cannot be made a step at a time, forced by logic and neutral experience. Like the gestalt switch, it must occur all at once (though not necessarily in an instant) or not at all." –
>
> Thomas Kuhn (1970)

5.2.4. Information and data management in design methods

There are several upcoming legislations such as the *Digital Product Passport*, *Corporate Sustainability Reporting Directive*, and *EU taxonomy*. This entails the need for sufficient and mature information and data management capabilities within product development and manufacturing organizations, such as accessibility to data to ensure traceability throughout the product's lifecycle. Furthermore, Rashid et al. (2013), also highlighted that resource-efficient, or circular, designs require extensive information and data exchange between organizational functions, and across the value chain. The descriptive framework, however, frames several barriers related to organizations' current information and data management capabilities, see core Category H ("Information and data capturing in *sustainable design practices*") and its related factors. The findings indicate that the current information and data management capabilities are insufficient to meet the increased demands that entail upcoming legislation and *sustainable design practices*.

[2] Shapira et al. (2017) tried to define such a *Sustainable design thinking*, but this proposal has not progressed since and it was neither focused on cognitive biases, nor proposed to be used on every level of an organization.

[3] "Everyone designs who devises courses of action aimed at changing existing situations into preferred ones" Simon (1969).

[4] "If you try to ensure long-term human well-being within the limits of the natural world, then you design for sustainability" Klotz et al. (2018).

This issue has been raised in previous literature (see e.g., Gmelin and Seuring, 2014; Chebaeva et al., 2021; Diaz et al., 2021). Parolin et al. (2024) also highlight the issue of insufficient real data for early phase assessments, but propose to "use real data if possible". Booker (2012) argued that a performance metric for design methods should be to what extent it utilizes available data, implying there is typically a lack of data. López-Mesa and Bylund (2011) also claim that new and improved design methods "require information that is not available in practice" along with a "lack of agreed vocabulary and taxonomy". Borsato (2014) refers to this barrier and introduces "ontology building", i.e., data and information that are represented differently need to be bridged to enable desired analyses. Mallalieu et al. (2022) also found that data and information incompatibility among different design methods can limit appropriate adoption. The above examples align with F44 ("Limited when there is lack of appropriate data") and F45 ("The information captured needs to be understood"). Furthermore, the empirical findings also indicated a misalignment between what practitioners perceived as possible, and what is practically feasible with the organization's current information and data management capabilities, see F50 ("Do not know what or how to capture"). Trevisan et al. (2023) also found a misalignment in their study, stating that IT departments had an insufficient understanding of sustainability, and the sustainability departments had insufficient competence related to IT. Schöggl et al. (2023), similarly, found discrepancies in how organizations align their digitalization and sustainability efforts among departments. This poses a risk where 'theoretically sustainable' designs are proposed, but infeasible in practice, resulting in *pseudo-sustainable designs*. This entails **Systemic barrier 2d:**

> Product development and manufacturing organizations' current information and data management capabilities are insufficient to adopt *sustainable design practices*. There is currently a misalignment between departments of what is practically feasible from an information and data management perspective, which risks leading to the proposal of *pseudo-sustainable designs*.

New and improved design methods can support improving the information and data management capabilities, see F51 ("design methods transfer understanding on 'how and what' sustainability relevant information and data to capture"). Design methods can, for example, be used to streamline terminology and how to structure information and data. Design methods can also clarify what information and data are required for different designs, supporting cross-functional collaboration by e.g., aligning expectations and clarifying practical feasibility between design, IT, and sustainability departments. Schöggl et al. (2023) also call for increased collaboration between IT and sustainability departments, and this study has shown that design methods can serve as effective means to facilitate such cross-functional collaboration. Furthermore, design methods have also been claimed as effective means to improve accountability, record keeping, and traceability (Araujo et al., 1996; Eder, 1998; Eder, 2009), which aligns with our study (see e.g., F48 "How methods were used need to be captured", and F49 "Who were part of the creating the results need to be captured"). This can, in turn, support organizations meeting upcoming legislation. Altogether, this entails **Proposition 2d:**

> Adopting new and improved design methods can support product development and manufacturing organizations to improve their information and data management capabilities, enabling more sustainable designs.

There is also a growing body of literature that focuses on emerging digital technologies that can support addressing some of the identified barriers related to information and data management capabilities (see e.g., Rusch et al., 2023; Han et al., 2023; Neri et al., 2023). Examples of emerging technologies include Internet of Things, blockchain technology, and big data analytics. Apart from emerging technologies, Rusch et al. (2023) and Schöggl et al. (2024b), promote inter-organizational collaboration combined with digital technologies to improve transparency and traceability (among other things) in the value chain. Trevisan et al. (2023), similarly, propose the concept of a circular ecosystem, which (among other things) aims to increase transparency and data sharing among collaborating actors in the value chain. Increased interaction and collaboration between actors in the value chain can be expected to enable the realization of more circular, and potentially sustainable designs (Schöggl et al., 2023; de Vasconcelos Gomes et al., 2024), but such collaboration has also been highlighted as challenging (see e.g., Schöggl et al., 2024a). Moreover, design methods have the potential to support such collaborative efforts, similar to how they can support internal cross-functional collaboration from an information and data management perspective. This entails **Proposition 2e:**

> Adopting new and improved design methods can facilitate collaboration between actors in the value chain from an information and data management perspective, enabling more sustainable designs.

6. Conclusion

This paper reports on an empirical study focusing on the adoption of *sustainable design practices* using design methods. Three product development and manufacturing organizations have been involved in multiple case studies, where qualitative data was collected using participant observation. Previous studies have provided several insights related to this topic, but the literature is scattered and divided across what we refer to as the design and management domains. This poses a research gap. This study therefore utilized an explorative and interdisciplinary approach using Glaserian grounded theory analysis and addressed the following research question: "What influences the adoption of *sustainable design practices* using new and improved design methods?". The research question is answered by identifying 53 interdisciplinary factors captured in a descriptive framework, which includes both process and methodological, organizational, and human-behavioral aspects. This study thus addresses the identified research gap. The empirical findings are also discussed and compared to interdisciplinary literature to further clarify and explain them. This results in nine **systemic barriers** and eight **propositions** that contribute to both theory and practice, which serve as our recommended actions and key issues to address by both research and practice. The key points are summarized below:

- Design methods are elaborated upon, where two new concepts referred to as the *dualism of design methods* and the *situational design problem* are introduced to better explain the identified barriers and enablers.
- Design methods address, or solve, *situational design problems* that share characteristics with *design problems*. This entails the *situational design problem paradox*, which limits a design method's applicability, highlighting that design methods' relevance varies, and their adoption always requires modification and adaptation.
- Practitioners are unable to see the value, or purpose, of new and improved design methods before they are adopted, which entails the *dualism of design methods paradox*.
- Design methods are prescriptive in their nature, which in turn results in natural human-behavioral barriers to their adoption.
- The process and methodological nature of product development and manufacturing organizations' current design practices are framed as a *paradigm of product design.* This entails the need for systemic organizational changes in such organizations to better align with *sustainable design practices*.
- Practitioners are urged to enter the *paradigm of sustainable design*, which requires a change of mindset, or attitude, with an increased social acceptance towards change.
- The presence of cognitive biases is highlighted and how it risks leading to an undesired state of *pseudo-sustainability*.

- The cognitive biases inside organizations must be challenged on all levels to enable the adoption of *sustainable design practices*.
- *Sustainable design thinking* is proposed and outlined as a potential enabler that aims to develop a base competence in sustainable design to systematically challenge the cognitive biases present in organizations.
- The information and data management capabilities of product development and manufacturing organizations limit the ability to adopt *sustainable design practices*.
- Design methods can facilitate collaboration and improve the information and data management capabilities of a value chain.

This research thus paves the way for future research with an interdisciplinary focus to further bridge the gap between the process and methodological, organizational, and human-behavioral perspectives. Future research should focus on assessing the validity of the **propositions** we provide in Sections 5.1 and 5.2. Five main topics require further attention specifically by future research: First, the role of cognitive biases in industry needs to be further studied as it risks leading to a state of *pseudo-sustainability*. Second, *Sustainable design thinking* requires further development and refinement such that it can be tested, evaluated, and used by practitioners. Third, information and data management in design methods is also a research topic that requires further attention. Fourth, design researchers and practitioners need prescriptive support in how to bridge the contextual gap, i.e., what we refer to as *contextual problems*, such that proposed design methods can be appropriately adapted to meet the practitioners' needs. Finally, the *paradigm of product design* would benefit from further verification by future empirical studies.

CRediT authorship contribution statement

Adam Mallalieu: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Sophie Isaksson Hallstedt:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Funding acquisition, Conceptualization. **Ola Isaksson:** Writing – review & editing, Writing – original draft, Supervision, Resources, Funding acquisition, Conceptualization. **Matilda Watz:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Investigation, Data curation, Conceptualization. **Lars Almefelt:** Writing – original draft, Visualization, Validation, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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