Formula for success? Design thinking for sustainability-oriented innovation in chemical companies

Plain language summary

Design thinking is an approach that is, amongst others, used to develop innovations. It could potentially be useful to develop sustainability-oriented innovation. This paper aims to answer the question: "*How is design thinking used for sustainability-oriented innovation at chemical companies?*" To answer this question, we collect 11 case studies from scientific literature of chemical companies that apply design thinking and analyse them using a new combination of frameworks. These frameworks tell us for which goals design thinking is used (product innovation or process innovation and focused on improving products and services or developing new ideas, products and services), as well as to which areas of sustainability the projects contribute (signified by the United Nations sustainable development goals (SDG's)).

We find that design thinking is used by different companies for a variety of purposes, of which many contribute to SDG's, even though sustainability is only mentioned explicitly as a goal in one of the papers. Examples of areas where design thinking contributed to SDG's are the design of improved healthcare products, development of more efficient green hydrogen production and better online tracking of herbicides to reduce pollution. We also found that design thinking is used for both improvement of existing products and development of new ideas. This is important, because companies need to focus on both of these to be successful now and in the future.

A pre-existing framework mentions three aspects that are crucial for companies to develop sustainability-oriented innovations. These are 1. collaboration between companies, 2. collaboration across different parts of a company, and 3. focus on the people that are affected by the innovation. Out of the 11 case studies that we analysed, 4 focused on collaboration between companies, 8 on collaboration across different parts of a company and 9 on people that are affected by the innovation. It seems that design thinking has the potential to develop these aspects. Therefore, we hypothesize that design thinking is inherently suited for sustainability-oriented innovation. This could be one of the reasons for the fact that the case studies contributed to several SDG's.

Finally, we searched for patterns in the case studies and found out that companies that focused on improving existing products rather than developing new ideas contributed to more SDG's on average. Similarly, companies that ran their own design thinking projects contributed to more SDG's on average than companies that relied on an outside expert to guide them. There is also a positive correlation between the duration of the practice (workshop, single project or permanent, in increasing order) and how many SDG's it contributed to. On the other hand, there was no difference between objects of innovation. Companies that focused on product or process innovation both contributed to approximately the same amount of SDG's on average.

The conclusions from this research are relevant, because they can help companies make decisions on whether and how to use design thinking for sustainability-oriented innovation, as well as giving scientists and design thinking facilitators an overview of the current applications.

Abstract

This paper explores how design thinking contributes to sustainability-oriented innovation in chemical companies. We utilize a new combination of frameworks to assess what contexts and application methods of design thinking by chemical companies are used for sustainability-oriented innovation. An evaluation of 11 case studies from chemical industry shows an equal representation of product and process innovation, as well as an equal representation of exploitative and explorative strategy (meaning a focus on improving products and services or developing new ideas, products and services, respectively). While sustainability is not a commonly mentioned goal in the case studies, they do contribute to multiple sustainable development goals (SDG's). We hypothesise that design thinking has a workflow that is inherently suited for sustainability-oriented innovations. This is supported by findings from our study, where collaboration between companies is mentioned in 4 cases, collaboration across disciplines, departments and hierarchies in 8, and people-focus in 9. These align with the systemic, integrated and people-focused aspects that are crucial for sustainability-oriented innovation according to literature. Additionally, an analysis of patterns between frameworks shows that for chemical companies in this study, exploitative design thinking projects, driven by an expert that is part of the company and permanently implemented, contributed to more SDG's on average than exploratory, externally driven or temporary projects. However, there are no significant differences in contribution between product- or process-focused applications. We advise chemical companies to take the findings from this study into account to optimize design thinking's potential for sustainability-oriented innovation.

1. Introduction

Sustainability-oriented innovation is becoming increasingly important for chemical companies. Changes such as stakeholders demanding corporate responsibility (Schniederjans & Khalajhedayati, 2023) and increasing regulatory pressures (European Commission, 2020; National science and technology council, 2023) are creating a new competitive landscape. Companies need sustainability-oriented innovation to ensure their competitiveness (Hermundsdottir & Aspelund, 2021), for now and for the future.

Literature repeatedly proposes the value of design thinking for sustainability-oriented innovation (Bocken et al., 2023; Buhl et al., 2019). This paper studies how design thinking is currently used for sustainability-oriented innovation at chemical companies by reviewing case studies from scientific literature. This could provide valuable insights in the current application and future potential of design thinking for sustainability-oriented innovation in chemical industry, for both scientist, managers and design thinking facilitators.

To our knowledge, one paper has previously been published reviewing design thinking in chemical industry (Piwowar-Sulej, 2020). However, due to the fast developments in chemical industry, we think a review of new publications and with an increased focus on sustainability-oriented innovation is valuable.

This article starts with a theoretical background of design thinking, including scientific literature on the benefits of applying it. Next, two innovation frameworks and two sustainability frameworks are introduced, with an extra section on the value of design thinking for sustainability-oriented innovations. The frameworks are subsequently used to evaluate eleven case studies of chemical companies applying design thinking. Thereby, we aim to assess how

design thinking is currently being used by chemical companies, and whether the case studies contributed to the United Nations sustainable development goals. Furthermore, we utilize a framework that describes aspects necessary for sustainability-oriented innovation to study how design thinking can facilitate sustainability-oriented innovation. Finally, we study correlations between the context and application methods in case studies of design thinking by chemical companies and contributions of those case studies to United Nations sustainable development goals. We aim to answer the following main question and four sub-questions:

How is design thinking used for sustainability-oriented innovation at chemical companies?

1. ***With what contexts and application methods is design thinking used at chemical companies?***
2. ***To which sustainable development goals do case studies of design thinking at chemical companies contribute?***
3. ***How can design thinking facilitate sustainability-oriented innovation?***
4. ***Which of the contexts and application methods are used most frequently for sustainability-oriented innovation?***

1.1 Design thinking

Initially, design thinking described the mindset and approach of designers. In the last 15 years, design thinking has been growing in popular use for a number of different applications (Baker & Moukhliss, 2020; Quaiser & Pandey, 2023). People now apply design thinking for instance in problem solving and innovation (Jaskyte & Liedtka, 2022), project management (Lahiri et al., 2021), or business management (Knight et al., 2020). There have been propositions to split the definition into distinct categories, for instance design thinking 1 and design thinking 2, or "Design Thinking" (with intentional capitalization) for the popular business approach and "designerly thinking" for the approach firmly rooted in design (Cross, 2023).

The multiple applications leads to ambiguity in the definition of design thinking (Baker & Moukhliss, 2020). To provide a coherent overview, we use the systematic review of Micheli et al. (2019). Based on extant literature and aided by professional designers, they characterize 10 principal attributes and 8 tools and methods of design thinking. The following section elaborates on the attributes (in *italics*). An overview is given in figure 1. It is worth noting that in most contexts, a selection of these attributes, tools and methods is used, not all of them.

Creativity and innovation are at the heart of design thinking (Darbellay et al., 2017). They are frequently reported as motivation for engaging in the design thinking process (Micheli et al., 2019). In fact, creativity and innovation are mentioned in every source that Micheli et al. analysed. Furthermore, design thinking often focuses on *solving wicked problems*. These are problems that are ill-formulated and complex, and where traditional linear problem solving is not effective (Matthews et al., 2023). One of the attributes that is used to deal with these wicked problems is a *systems view* to gain a deeper understanding of the system in which the problem is embedded (Mononen, 2017). People that use a systems view acknowledge that different parts of the system (e.g. different people, environment or companies) influence each other and that an understanding of the entire system is necessary to truly solve a problem (Arnold & Wade, 2015).

Design thinking is frequently applied in *interdisciplinary* teams, in order to provide different perspectives and to create stakeholder engagement throughout the project (Darbellay et al.,

2017). *Blending of analytical methods with intuition* provides a dynamic balance. Data is gathered and interpreted, but gut-feeling is considered equally important, especially when dealing with wicked problems as mentioned before. *Abductive reasoning* is often used to reframe problems and allow for the creation of new insights when no analytical data is available (Vignoli et al., 2023).

One of the fundamental features of design thinking is *human-centeredness* (Lahiri et al., 2021). Experiments are often used to gain insight into the people that will be interacting with the solutions. Frequently, a process called co-creation is applied, where those people are invited to participate in the design thinking process. Here, the *ability to visualize* is essential to communicate ideas early on and to build further on them. Finally, people applying design thinking are encouraged to be *tolerant of ambiguity and failure* (Vignoli et al., 2023). Not every assumption is correct, nor is every solution successful, design thinking encourages people to accept this and to continue the process until a successful innovation is created.

There are many different models for the design thinking process (Waidelich et al., 2018), but it can generally be divided into three main stages, with sub-stages depending on the model. The first stage is immersion in the problem, with an empathetic focus on the person who experiences the problem. The second is ideation, using problem framing and visualization. Finally, the third stage is prototyping and experimentation (Liedtka, 2015; Rösch et al., 2023). These stages are not always followed sequentially. The design thinking process is characterized by the ability to go back to previous stages and *iteratively* cycle between them.

The attributes are supported by a range of tools and methods, such as ethnographic methods, personas, journey maps, brainstorming, mind maps, visualisation, prototypes and experiments (Micheli et al., 2019). The tools are applied according to the situation, often guided by a professional.

This paper examines the use of design thinking as an approach for any innovation object (where we define innovation as the process of developing and introducing new elements or improving upon existing ones (O'Reilly & Tushman, 2004)), ranging from design to problem solving or business management.

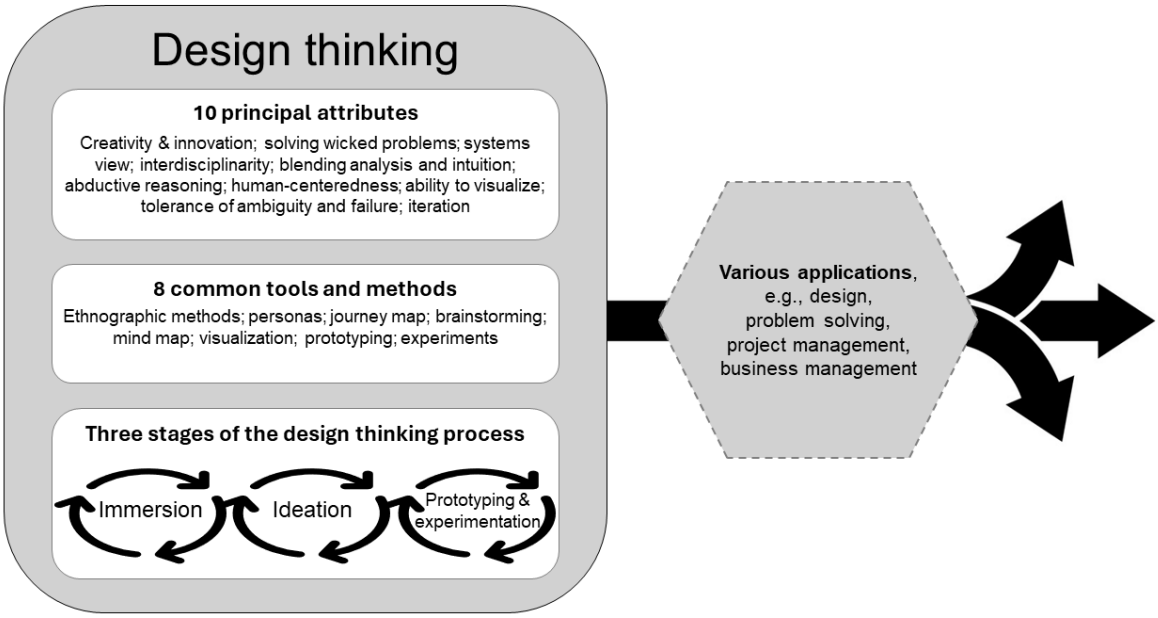


Figure 1. *Overview of design thinking. 10 principal attributes and 8 common tools and methods of design thinking were determined by Micheli et al. (2019). Three stages of the design thinking process are a synthesis based on Rösch et al. (2023). The stages can be iteratively revisited, shown by the circular arrows. Design thinking is varied in both its definition and its applications, but this figure aims to give a general overview.*

The benefits of design thinking

A broad basis of scientific literature shows benefits of design thinking. Design thinking for new product development is positively associated with product quality (Meinel et al., 2020; Nagaraj et al., 2020). Interestingly, Elsbach & Stigliani (2018), find that the experiential nature that is inherent in design thinking allows people to support one another. Furthermore, design thinking has a beneficial effect on psychological empowerment, which in turn improves project performance (Roth et al., 2020). Design thinking practitioners report positively on multiple beneficial outcomes, including positive effects on the team and on the performance of newly developed products/services (Jaskyte & Liedtka, 2022; Nakata & Hwang, 2020).

1.2 Innovation

In the following two sections (1.2 innovation and 1.3 sustainability), we introduce four frameworks. Figure 2 shows an overview of the four frameworks, categorised by innovation or sustainability and by object or strategy. The combination of the four frameworks helps with understanding the ways that design thinking is currently being used by chemical companies, the contributions to United Nations sustainable development goals, and the potential of design thinking for sustainability-oriented innovation.

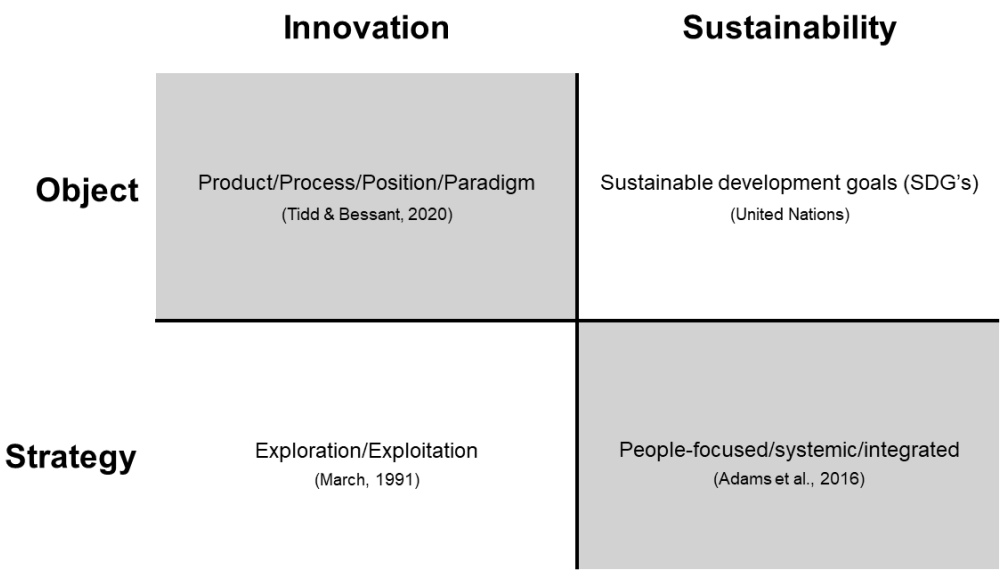


Figure 2. *Overview of the four sustainability frameworks used in this paper to evaluate case studies of chemical companies applying design thinking.*

Innovation frameworks

To identify the ways in which chemical companies use design thinking, two frameworks of innovation are considered in this review. Tidd & Bessant (2020) define a framework with four innovation objects: product, process, position and paradigm. We use this first framework to show for what kind of purposes design thinking is used by chemical companies.

- *Product: products or services (what is delivered to the end-user?)*
- *Process: production or delivery methods (how does the product or service come to be?)*
- *Position: context (the story around the product or service, e.g. who is it for?)*
- *Paradigm: framing (changes in underlying mental models of what the organization does)*

The second framework compares exploratory and exploitative innovation (March, 1991). Exploratory innovation involves discovery, risk taking and flexibility, while exploitative innovation involves refinement, efficiency and implementation.

A balance between these two strategies is essential for business success in the short and long term. Therefore, O'Reilly & Tushman (2004) introduced the term ambidextrous innovation, the ability to balance simultaneous exploration and exploitation. For the chemical industry, Bauer & Leker (2013) identified an optimal balance between exploratory and exploitative R&D approaches, with this balance differing between process and product innovation. That paper also shows the example of DuPont, a chemical company that saw an income decrease of 40% over 5 years as a result of excessive focus on exploitation at the expense of exploration. Thus, ambidexterity is important for business success. Previous literature shows that design thinking facilitates ambidexterity (Nielsen et al., 2021; Randhawa et al., 2021; Zheng, 2018).

1.3 Sustainability

This paper focuses on sustainability-oriented innovation (SOI). This encompasses innovation in either an organization's philosophy or its product/services, and aims at the 'triple bottom

line' of not only economic gain, but also gain within social and environmental dimensions (Adams et al., 2016). However, SOI is not an end point but an *orientation*, since sustainability impacts of innovations are highly uncertain. Hansen & Große-Dunker (2013) give the example of biofuels which were regarded as sustainable, until negative aspects such as monocultures, loss of biodiversity and impacted food prices started showing. In this paper, we consider contributions to United Nations sustainable development goals as a measure for the sustainability orientation of an innovation, as will be explained later in this section.

Design thinking for sustainability-oriented innovation

Buhl et al. (2019) show the value of design thinking for developing SOI by identifying four major challenges of SOI that design thinking addresses, namely innovation scoping, identifying user needs, stakeholder involvement, and assurance of sustainability effect.

Design thinking is already used for a variety of sustainable purposes by businesses outside of the chemical industry, for example to reduce environmental impact of aged care, to increase efficiency and sustainability of industry wastewater treatment, or to improve social sustainability of mining (Clune & Lockrey, 2014; Lee et al., 2023; Sinan Erzurumlu & Erzurumlu, 2015).

Furthermore, a multitude of frameworks have been developed to apply design thinking for sustainable development, sustainable circular innovation, circular business model innovation or strategic sustainable development (Baldassarre et al., 2024; Bocken et al., 2023; Santa-Maria et al., 2022; Shapira et al., 2017). We refer to those individual papers for elaboration, since summaries would not do them justice.

Even though design thinking is repeatedly proposed for sustainable purposes, the focus in design thinking literature is not predominantly on sustainability. Baldassarre et al. (2024) shows that in extant literature on design thinking as an innovation management approach, the focus is primarily (90%) on economic impact, with 40% of papers focusing on social impact and only 7% on environmental impact.

Sustainability frameworks

To evaluate the case studies for their focus on sustainability-oriented innovation, two frameworks are used. Firstly, contributions to the United Nations sustainable development goals (SDG's) are used to evaluate how much the objects of the case studies are oriented towards sustainability. This framework is chosen because of its comprehensive scope of sustainability. The SDG's are 17 goals related to various aspects of society and the environment. Their titles are: No poverty (1), Zero hunger (2), Good health and well-being (3), Quality education (4), Gender equality (5), Clean water and sanitation (6), Affordable and clean energy (7), Decent work and economic growth (8), Industry, innovation and infrastructure (9), Reduced inequalities (10), Sustainable cities and communities (11), Responsible consumption and production (12), Climate action (13), Life below water (14), Life on land (15), Peace, justice, and strong institutions (16), and Partnerships for the goals (17) (United Nations, 2015).

Secondly, the model for sustainability-oriented innovations by Adams et al. (2016) is used to evaluate the sustainability strategy of the companies. Adams et al. propose three categories for sustainability-oriented innovations. In increasing level of sustainable impact, these are: operational optimization, organizational transformation and systems building. Crucially, when

moving from the first to the third category, activities shift from insular/stand-alone/technical to systemic/integrated/people-focused (figure 3). We identify mentions of the latter three aspects in the description of the case studies, because they are explicit and can be easily identified, in contrast to the three categories. It should be noted that a focus on any of these aspect does not necessarily imply a mastery of that aspect. Nevertheless, it evaluates the potential of design thinking for facilitating sustainability-oriented innovation at chemical companies.

Additionally, the combination of the two innovation frameworks and the two sustainability frameworks gives us an indication of the way that design thinking is applied by chemical companies, as well as the correlation between the way of application and the contribution to SDG's.

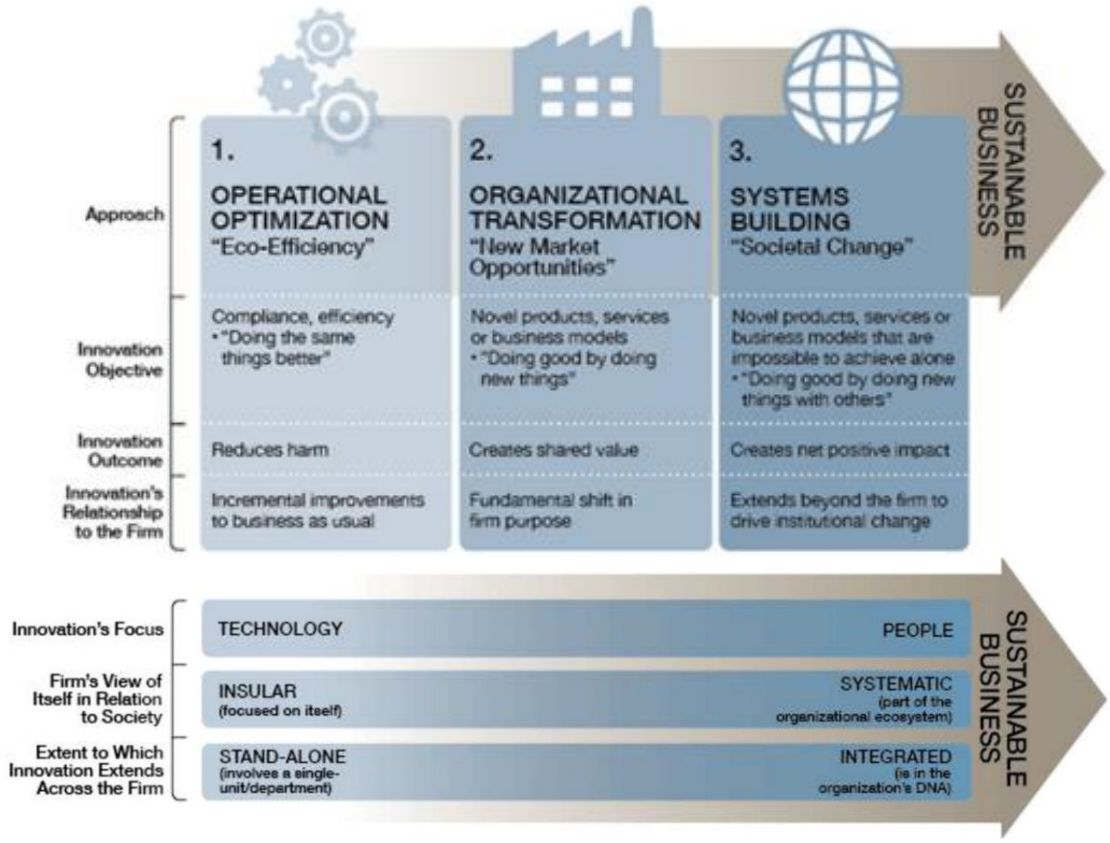


Figure 3. *Model for sustainability-oriented innovations in companies. Three general categories of sustainability-oriented innovation in companies are defined at the top, as well as three aspects at the bottom that are crucial for companies to move from the first towards the third category. Image from Adams et al. (2016).*

2. Methods

This paper looks for case studies of chemical companies applying design thinking, as these give a representation of the application of design thinking in companies, in contrast to theoretical frameworks. A search term was crafted to include as many case studies from chemical companies as possible, while excluding use of design thinking by students, which is a frequent object of scientific articles. Furthermore, "human-centered design" was incorporated in the search term, since case studies often use the term interchangeably with design thinking.

The final search term was variable, with the following main structure: *"Design thinking" OR "Human-centered design" AND [x] NOT Students*. In this search term, *[x]* was substituted for *"chem*"* or common sub-categories of chemical industry (*Petrochem*, oil, pharma*, polymer*, plastic, fertiliser, cosmetics, pesticide, coating, adhesive, sealant, gas, acid, alkali* (based on author's insight)) or world-leading chemical enterprises (*BASF, DOW, LyondellBasell, LG chem, Nutrien, Mitsubishi, Linde, Air Liquide, Umicore, Hengli, Bayer, Merck* (Statista research department, 2023)).

The search was conducted via Scopus, Web of Science and Google scholar. The selection was limited to scientific papers with explicit mention of design thinking or human-centered design being applied by companies in chemical industry. This was defined to include pharmaceutical and petrochemical companies, but excluded the use of design thinking by students.

Nine papers with a total of eleven case studies were found that match the selection criteria, as well as five related papers that do not meet criteria but are relevant to mention. In the next paragraphs, a summary of the case studies in alphabetical order is given. Table 1 shows an overview of the eleven selected case studies with information on sector, company size, the department using design thinking, the design thinking driver (whether the expert that is driving the design thinking practice is internal to the company or external, like a consultant or design firm) and the duration of the design thinking implementation. Furthermore, the eleven selected case studies are evaluated for innovation object (product, process, position or paradigm), innovation strategy (exploratory or exploitative), sustainability object (contribution to SDG's) and sustainability strategy (based on Adams et al., 2016). The results are shown in table 2.

The evaluation is done based on the author's insight. For innovation object and strategy, quotes are used as proof for the categorization (Table A1 in the appendix). Explanation for the contribution to SDG's is shown in table A2 in the appendix, and is based on reporting from the case studies, identified by the author.

3. Results

Berger & Merindol (2019) investigate organizational impacts of design thinking and show amongst others a case study of design thinking in the innovation lab of a world leader in industrial gases, with the goal of developing radical innovation. Innovators work together with other departments and spread design thinking practices.

Birkinshaw et al. (2018) show the innovation program in a large chemical enterprise. Innovation trainings include design thinking to drive customer-centricity for employees throughout the company.

Janz & Brittain (2017) describe how human-centered design helped the IT department of a big pharmaceutical company become more entrepreneurial. It shows a case study of innovating on the custom fit orthotic kiosk, where the IT department could take an active role in the design process. The process elicited new solutions, which resonates with users and could result in significant new revenue streams.

Malynovska et al. (2021) improved the personnel certification procedures at a university of oil and gas with the use of design thinking (there is no mention however of design thinking being applied in the courses at the university). They changed selection of applicants and increased study time for solving typical tasks. This led to an improved ratio of passed qualification exams.

Santos et al. (2018) describe design thinking in a co-creation process between a multinational perfumer and two companies in the fine chemical sector. Design thinking facilitated co-creation and provided agility in the development of a new perfume.

Waerder et al. (2017) provided design thinking guidance for three companies in the chemical industry. These focused on user experience of SAP architecture (SAP is a company for business software), improved tracking of herbicides, and exploration of business opportunities with the artificial intelligence trend, consecutively. They found that design thinking helped interdisciplinary collaboration and led to impressive ideas.

Watterson et al. (2022) describes the continuous collaboration between a design company and a pharmaceutical company on improving the design of insulin pens. They describe that they developed pens that are more discrete or refillable.

Yorgun et al. (2023) gave a design thinking workshop to improve collaboration between 16 partners. They are working on developing an automated production assembly line for an electrolyser stack to produce green hydrogen. This led to new designs and more enjoyable work.

Yuhun et al. (2023) use design thinking with scrum (an agile form) to optimise drilling operations with a digital application. Specifically, they optimised collaboration between teams and found savings in both cost and CO2 emissions.

Table 1 shows an overview of all these case studies, with information on the sector, company size, the department that is using design thinking, the driver of design thinking and the duration of the design thinking implementation.

Source	Sector	Company size	Department using design thinking	Design thinking driver	Duration
Berger & Merindol (2019)	Industrial gases	World leader	Innovation Lab. Collaboration + intrapreneurship. Now spreading	Internal	Permanent
Birkinshaw et al. (2018)	Pharma, health & agricultural chemistry	Large enterprise	Systemic, training employees	Internal	Permanent
Janz & Brittain (2017)	Consumer-based pharma	One of the largest in the world	IT, collaboration with other departments	Internal	Permanent
Malynovska et al. (2021)	Petrochem certification	Medium-size university	Personnel certification	Internal	Single project
Santos et al. (2018)	Perfume, in collaboration with fine chemicals	Multinational and market leader	Product development	Internal	Single project
Waerder et al. (2017)	Specialty chemicals	Leading, global vendor	IT, collaboration with members from different departments	External	Workshop
	Agricultural chemistry	Top 10 chemical company	Various subject matter experts	External	Single project
	Specialty chemicals	Mid-sized	IT, collaboration with German research center for AI, DFKI	External	Workshop
Watterson et al. (2022)	Pharma	Big international enterprise	External design and innovation company	External	Permanent
Yorgun et al. (2023)	Hydrogen electrolyser manufacturing	Collaboration with multiple partners, varying in size	Ruhr-University Bochum with 16 partners	Internal	Workshop
Yuhun et al. (2023)	Petrochem	Not specified	Drilling	Internal	Single project

Table 1. *Context information on chemical companies applying design thinking that are mentioned in the case studies literature. The design thinking driver is the expert that is driving the design thinking practice, which can be in the company or an outside party, like a consultant or design firm.*

Other literature

Some papers did not meet the selection criterium of describing a chemical company applying design thinking, but we still deem them valuable to mention here. Barateiro et al. (2012) discuss the potential use of human-centered design for control process automation of petrochemical plants. Mehta & McCay (2015) designed personal protective equipment for the application of pesticides in India. Mikkelsen & Lange (2017) propose design scenarios for the re-use of decommissioned oil rigs. Wilson et al. (2022) describe opportunities for the reduction of plastic waste using design thinking. Finally, Lager & Fundin (2022) surveyed 19 companies in the process industries, including 5 in the chemical industry, on the use of innovation methodologies. No details are given about the companies, but they found that one chemical companies uses design thinking and one uses a process similar to design thinking. The results also show that informants are sincerely interested in innovation methodologies and four out of five would recommend the application of design thinking in an enhanced product innovation work process.

3.1 Innovation

As mentioned before, four innovation objects can be distinguished: product, process, position or paradigm. Within the selection of case studies on design thinking in chemical industry, some companies focus on explicit product innovation (Janz & Brittain, 2017; Santos et al., 2018; Watterson et al., 2022). This is understandable given the roots of design thinking in design practice. Next to this, companies also use design thinking for innovating in processes (Malynovska et al., 2021; Waerder et al., 2017 (1st case study); Yuhun et al., 2023). Interestingly, some companies start integrating design thinking not just in product or process design, but also spread the practices to other departments (Berger & Merindol, 2019; Birkinshaw et al., 2018).

Furthermore, the innovation can focus on exploratory or exploitative strategy. The two categories are equally represented in the selection of case studies. Furthermore, no clear pattern can be found to link the innovation strategy to the innovation object. Product innovation can be exploratory or exploitative, as can process innovation. Design thinking is used in a versatile manner for various kinds of innovation. Table 2 shows the innovation object and strategy for the selected case studies, as well as the contribution to SDG's, which will be elaborated in the next section. Table A1 in the appendix shows quotes as proof for the categorization.

Source	Innovation object	Innovation strategy	Contribution to SDG's	Sustainability strategy		
				Systemic	Integrated	People-focused
Berger & Merindol (2019)	Any object	Exploratory			+	+
Birkinshaw et al. (2018)	Paradigm, product & process	Undefined			+	+
Janz & Brittain (2017)	Position & product	Ambidextrous			+	+
Malynovska et al. (2021)	Process & product	Exploitative			+	+
Santos et al. (2018)	Paradigm & product	Exploratory		+	+	+
Waerder et al. (2017)	Process	Exploitative			+	
	Product	Exploitative			+	+
	Paradigm	Exploratory		+		
Watterson et al. (2022)	Product	Exploitative		+		+
Yorgun et al. (2023)	Process	Exploratory		+		
Yuhun et al. (2023)	Process	Exploitative			+	+

Table 2. *Evaluation for the evaluated case studies of chemical companies applying design thinking, on innovation object and innovation strategy, as well as contribution to SDG's and sustainability strategy. 'Systemic' denotes collaboration between companies, 'integrated' denotes collaboration across disciplines, departments and hierarchies. For further elaboration on the categorizations, see table A1 and A2 in the appendix.*

3.2 Sustainability

Within the selection of case studies, the only paper that explicitly mentions sustainability as a goal is Yorgun et al. (2023), which focuses on green hydrogen production. However, most case studies report contributions to SDG's as part of their process or resulting products. For example, innovations in pharmaceutical R&D are developed with the desires of patients in mind, which help these patients live a healthy life and feel like everyone else (Janz & Brittain, 2017; Watterson et al., 2022). Furthermore, design thinking leads to more enjoyable work (Janz & Brittain, 2017; Yorgun et al., 2023), and yields efficient results (Malynovska et al., 2021; Yuhun et al., 2023). Importantly, improvements in design of products or processes can help contribute to SDG's. For example, refillable products (Watterson et al., 2022), CO2 reduction (Yuhun et al., 2023) or better tracking of herbicides (Waerder et al., 2017 (2nd case study)). Table 2 shows the contribution of the selected case studies to SDG's. An overview ordered by SDG's is added in the appendix.

Interestingly, even though sustainability is not an explicit goal, many of the case studies are quite advanced on the scale of sustainability-oriented innovations by Adams et al. (2016). In the case studies, one of the most frequently mentioned advantages of design thinking is an increase in collaboration across disciplines, departments and hierarchies (8 out of 11), or even between companies (4 out of 11). Finally, 9 out of 11 case studies mention focus on people. This shows that design thinking facilitates a shift from insular/stand-alone/technical to systemic/integrated/people-focused.

Correlation between application type and contribution to SDG's

In this section, we evaluate the correlation between application type of design thinking and the average amount of SDG's that the project has contributed to. This gives an indication as to which application type of design thinking is used the most for sustainability-oriented innovations, but does not consider the size of the impact, nor which application type is most effective for sustainability impact.

Within these case studies, there is no significant difference between product and process innovation on how many SDG's they contribute to (average 1⅔ and 1⅗ SDG per case study, consecutively). Paradigm and position innovation are underrepresented in the selection, so they are not considered. On the other hand, exploitative projects clearly contribute to more SDG's on average than explorative projects (average 1⅖ and ¾ SDG per case study, consecutively).

The context information of the case studies give further information about the application of design thinking that is used the most for sustainability-oriented innovations. The two case studies on specialty chemicals do not contribute to SDG's, for example. However, the small amount of case studies in this paper make it impossible to draw hard conclusions about sector, company size or department. On the other hand, there are clear patterns in design thinking driver and duration of the design thinking implementation. Internally driven projects contribute to more SDG's on average than externally driven projects ($1\frac{5}{7}$ and ¾ SDG per case study, consecutively) and permanent incorporation of design thinking (2 SDG per case study) contribute to more SDG's on average than a single project (1¼) or a workshop (⅔). Table 3 gives an overview of the results.

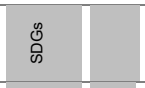
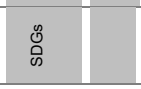
		Average amount of SDG's contributed	Nr of case studies
Innovation object	Product		6
	Process		5
Innovation strategy	Exploitative		5
	Explorative		4
Design thinking driver	Internal		7
	External		4
Duration	Permanent		4
	Single project		4
	Workshop		3

Table 3. *Average amount of sustainable development goals that the analysed case studies of chemical companies applying design thinking contributed to, grouped by categories.*

4. Discussion

1. ***With what contexts and application methods is design thinking used at chemical companies?***

We found that in our selection of case studies, design thinking is used in a variety of fields. It is applied for product and process design, but also to change the paradigm of a company. The departments applying it are varied, there are multiple IT-departments applying design thinking but it is also often used for collaboration between departments or even between companies. The strategy is equally distributed between exploration and exploitation, showing the possibility of developing an ambidextrous innovation portfolio using design thinking, which corresponds with conclusions from previous literature (Nielsen et al., 2021; Randhawa et al., 2021; Zheng, 2018). Design thinking is frequently driven by an expert in the company (7 times), rather than an external expert, like a consultant or design firm (4 times). Furthermore, there is an approximately equal distribution between different durations of the practice: permanent (4), single project (4) or workshop (3).

2. ***To which sustainable development goals do case studies of design thinking at chemical companies contribute?***

Even though sustainability was not a commonly mentioned goal in the selection of case studies, a lot of them contributed to SDG's in one way or another. The results include pharmaceutical products such as orthotics that improve health (SDG 3) and insulin pens that are refillable to reduce waste (SDG 12) or that are unrecognizable as insulin pens to make people with diabetes feel like everyone else (SDG 3). Other studies worked on green hydrogen production (SDG 7), optimised drilling operations which also happened to reduce CO2 emissions (SDG 13), or improved tracking of herbicides (SDG 15).

Furthermore, design thinking could have positive effects for other parts of the chemical industry value chain. For instance, design thinking could be a valuable methodology for chemical industry to take responsibility for the end-of-life of their products, such as old infrastructure and plastics (Mikkelsen & Lange, 2017; Wilson et al., 2022). Furthermore, the interconnectedness of global markets necessitates consideration of the people in developing regions that are associated with chemical industry, including those controlling petrochemical plants (Barateiro et al., 2012) and farmers applying pesticides (Mehta & McCay, 2015).

3. ***How can design thinking facilitate sustainability-oriented innovation?***

We hypothesise that one of the reasons for the contributions to SDG's is that design thinking has a workflow that is inherently suited for sustainability-oriented innovations. The framework of Adams et al. (2016) was used to assess the case study on three aspects that are necessary for sustainability-oriented innovation: systemic, integrated and people focused. These aspects were frequently mentioned in case studies (8, 4 and 9 times, consecutively), which supports our hypothesis.

However, a mention does not necessarily imply a mastery of that aspect. Every company falls somewhere on the scale from insular/stand-alone/technical to systemic/integrated/people-focused. A mention of one of these aspects suggests, but does not ensure, that the case studies are working to position themselves further to the right on these scales. If they are, that could be valuable in achieving sustainability-oriented innovation.

4. Which of the contexts and application methods are used most frequently for sustainability-oriented innovation?

We found that, within our selection of case studies, certain contexts and application types (exploitative, internally driven, permanently incorporated) contribute to more SDG's on average than their respective opposites. Therefore, we conclude that within our selection of case studies on chemical companies applying design thinking, those contexts and application types are used the most for sustainability-oriented innovation. No conclusions can be drawn about the context or application method that is the most effective for sustainability impact, but our results do give an indication of the current state in the chemical industry of applying design thinking for sustainability-oriented innovations.

Limitations and recommendations

It is important to note that the contributions to SDG's were determined by the author based on the case studies' own reporting. We emphasize that these contributions do not necessarily correlate with amount of sustainability impact. However, they were deemed by the author to be, at the very least, *oriented* towards SDG's, and if the reporting from the case studies are true, lead to contributions towards SDG's. Future studies could aim at objectively quantifying impact on sustainability goals, in order to draw more definite conclusions.

Furthermore, all categorizing of context, application methods and contribution to SDG's was performed by a single author. The appendices show elaboration on these choices. Still, in this way, the results cannot be considered completely objective. To improve the results, multiple authors could determine contexts, application methods and SDG's independently, and compare their results.

It could be argued that some of the case studies are not traditionally chemical. However, it is clear that the chemical industry has expanded beyond just the lab. Companies can get a competitive advantage not just by offering good chemicals, but also by designing for the people that use their products or services.

We also underline that design thinking is not just a clear-cut toolbox (Cross, 2023). Instead, it should be adapted to the situation in which it is applied. Berger & Merindol (2019) mention that the case company found it valuable to recruit a professional designer, who masters the methods and tools. Furthermore, Janz & Brittain (2017) mention that patience is necessary to integrate breakthrough ideas and it is important to involve key stakeholders early-on.

This study aimed at finding the ways that design thinking contributes to sustainability-oriented innovation. Not surprisingly, most literature and the analysed case studies report positively on design thinking. However, to achieve a more objective view, the negative side should be equally considered. Future research could introduce design thinking into a company and report in-depth on positive or negative developments, using standardized quantitative measures. These studies should track measures on profits and costs, innovation types and sustainable impacts.

Finally, we urge other scientists to use the framework combination that we introduced in this paper and improve on it where necessary. It could be used to review the aspects, context and application methods of design thinking in other fields, but also to review other innovation methods. This might show that results are generalizable across sectors and across innovation methods or that certain methods are better suited for a specific sector.

5. Conclusion

How is design thinking used for sustainability-oriented innovation at chemical companies?

In conclusion, sustainability is generally not the initial purpose for the use of design thinking by the chemical companies in these case studies. However, the case studies show improvements in products and processes relating to various SDG's. Furthermore, the methodology has inherent qualities that make it suited for sustainability-oriented innovations by improving collaboration (across disciplines, departments and hierarchies; and also between companies) and focusing on the people that are affected by the innovation. Finally, some application types of design thinking clearly contribute to more SDG's on average than others. Exploitative, internally driven and permanently incorporated design thinking by chemical companies in this study all contribute to significantly more SDG's on average than their respective opposites.

The findings of this study give an indication of the current application at chemical companies of design thinking for sustainability-oriented innovation. Therefore, we urge chemical companies, scientists, and design thinking experts to take these findings into account. Next to advancing scientific knowledge, the findings could help with decisions on whether and how to apply design thinking, now that sustainability-oriented innovation is becoming increasingly important for chemical companies.

Appendices

Source	Innovation object	Quote	Innovation strategy	Quote
Berger & Merindol (2019)	Any object	"work with marketing, engineering and production functions as well as start-ups"	Exploratory	"a creative toolkit for developing exploratory projects"
Birkinshaw et al. (2018)	Paradigm, product & process	"core methodologies to drive innovation" "drive product, process and business-model innovation"	Undefined	-
Janz & Brittain (2017)	Position & product	"expose the product line to a new untapped customer base" "market testing suggests the new product will result in a significant new revenue stream."	Ambidextrous	"further innovate on the CFO platform" "The HCD process elicited new, alternative solutions"
Malynovska et al. (2021)	Process & product	"the procedures for selecting, training and conducting a qualification exam"	Exploitative	"improving certification procedures"
Santos et al. (2018)	Paradigm & product	"the paradigm shift with co-creation and design thinking strategies in such a knowledge and technology intensive industry maximized new products development process."	Exploratory	"the development and launch of a new perfume"
Waerder et al. (2017)	Process	"UX for the existing SAP architecture"	Exploitative	"the further development of the system"
	Product	"Design ideas for the UI were developed, that consisted of appropriate functionalities for the end user."	Exploitative	"Even though the parent company provides a Supply Chain Track & Tracing System, the different basic components are not satisfactorily integrated"
	Paradigm	"The IT department […] identified a profit and growth potential for their company due to the "Artificial Intelligence" trend."	Exploratory	"They wanted to explore and evaluate the opportunity"

Watterson et al. (2022)	Product	"The development of insulin pens"	Exploitative	"to continually improve the design of their insulin pens"
Yorgun et al. (2023)	Process	"develop a prototype of a production line for the fully automated assembly of a PEM-electrolyzer stack"	Exploratory	"the creation of a rough production line"
Yuhun et al. (2023)	Process	"Well-factory drilling workflow"	Exploitative	"the application was built to streamline and transform our linear well-factory drilling workflow"

Table A1. *Evaluation of innovation object and strategy for the evaluated case studies of chemical companies applying design thinking. Quotes are presented as proof for the categorisation.*

SDG	Contributions to SDGs mentioned in case studies of design thinking	Sources mentioning beneficial results
	Human-centric pharmaceutic innovations	(Janz & Brittain, 2017; Watterson et al., 2022)
	Better education (teaching DT or improving education with DT)	(Birkinshaw et al., 2018; Malynovska et al., 2021)
	Green hydrogen	(Yorgun et al., 2023)
	Better (more effective and enjoyable) work environment	(Janz & Brittain, 2017; Malynovska et al., 2021; Yorgun et al., 2023; Yuhun et al., 2023)
	Radical innovation	(Berger & Merindol, 2019; Birkinshaw et al., 2018; Janz & Brittain, 2017)
	Collaboration across disciplines, departments and hierarchies	(Berger & Merindol, 2019; Birkinshaw et al., 2018; Janz & Brittain, 2017; Santos et al., 2018; Waerder et al. (1st & 2nd), 2017; Yuhun et al., 2023)
	Reusable/refillable products	(Watterson et al., 2022)
	CO2 reduction	(Yuhun et al., 2023)
	Better tracking of herbicides	(Waerder et al., 2017 (2nd))
	Collaboration between (competing) companies	(Santos et al., 2018; Waerder et al., 2017 (3rd); Watterson et al., 2022; Yorgun et al., 2023)

Table A2. *Contributions to sustainable development goals mentioned in case studies of design thinking at chemical companies. Determined by authors based on mentions of contributions in case studies.*

References

Adams, R., Jeanrenaud, S., Bessant, J., Denyer, D., & Overy, P. (2016). Sustainability-oriented Innovation: A Systematic Review. *International Journal of Management Reviews*, *18*(2), 180–205. https://doi.org/10.1111/ijmr.12068

Arnold, R. D., & Wade, J. P. (2015). A Definition of Systems Thinking: A Systems Approach. *Procedia Computer Science*, *44*, 669–678. https://doi.org/10.1016/j.procs.2015.03.050

Baker, F. W., & Moukhliss, S. (2020). Concretising Design Thinking: A Content Analysis of Systematic and Extended Literature Reviews on Design Thinking and Human-Centred Design. *Review of Education*, *8*(1), 305–333. https://doi.org/10.1002/rev3.3186

Baldassarre, B., Calabretta, G., Karpen, I. O., Bocken, N., & Hultink, E. J. (2024). Responsible Design Thinking for Sustainable Development: Critical Literature Review, New Conceptual Framework, and Research Agenda. *Journal of Business Ethics*. https://doi.org/10.1007/s10551-023-05600-z

Barateiro, C. E. R. de B., Filho, J. R. de F., & Campagnac, L. A. da P. (2012). The Complexity and the User: The Human Centered Design Approach as a Paradigm for This Integration. *The China Business Review*, *11*(12). https://doi.org/10.17265/1537-1514/2012.12.007

Bauer, M., & Leker, J. (2013). Exploration and exploitation in product and process innovation in the chemical industry. *R and D Management*, *43*(3), 196–212. https://doi.org/10.1111/radm.12012

Berger, E., & Merindol, V. (2019). The Organizational Impacts of Design Thinking used as a Toolbox for Managers or as a Theory of Design. *Conference Proceedings of the Academy for Design Innovation Management*, *2*(1). https://doi.org/10.33114/adim.2019.02.204

Birkinshaw, J., De Diego, E., Trill, H., & Hitzbleck, J. (2018). Bayer's Innovation Agenda: Igniting Innovation in a 100,000-person company. *London Business School*.

Bocken, N., Baldassarre, B., Keskin, D., & Diehl, J. C. (2023). Design thinking tools to catalyse sustainable circular innovation. In *The Routledge Handbook of Catalysts for a Sustainable Circular Economy* (pp. 359–387). Routledge. https://doi.org/10.13140/RG.2.2.14365.08162

Buhl, A., Schmidt-Keilich, M., Muster, V., Blazejewski, S., Schrader, U., Harrach, C., Schäfer, M., & Süßbauer, E. (2019). Design thinking for sustainability: Why and how design thinking can foster sustainability-oriented innovation development. *Journal of Cleaner Production*, *231*, 1248–1257. https://doi.org/10.1016/j.jclepro.2019.05.259

Clune, S. J., & Lockrey, S. (2014). Developing environmental sustainability strategies, the Double Diamond method of LCA and design thinking: A case study from aged care. *Journal of Cleaner Production*, *85*, 67–82. https://doi.org/10.1016/j.jclepro.2014.02.003

Cross, N. (2023). Design thinking: What just happened? *Design Studies*, *86*. https://doi.org/10.1016/j.destud.2023.101187

Darbellay, F., Moody, Z., & Lubart, T. (2017). *Creativity, Design Thinking and Interdisciplinarity*. Springer Nature.

Elsbach, K. D., & Stigliani, I. (2018). Design Thinking and Organizational Culture: A Review and Framework for Future Research. *Journal of Management*, *44*(6), 2274–2306. https://doi.org/10.1177/0149206317744252

European Commission. (2020). *Chemicals strategy for sustainability*.

Hansen, E. G., & Große-Dunker, F. (2013). Sustainability-Oriented Innovation. In *Encyclopedia of Corporate Social Responsibility* (pp. 2407–2417). Springer. https://doi.org/10.1007/978-3-642-28036-8_552

Hermundsdottir, F., & Aspelund, A. (2021). Sustainability innovations and firm competitiveness: A review. In *Journal of Cleaner Production* (Vol. 280). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2020.124715

Janz, B. D., & Brittain, M. J. (2017). Incorporating Human-Centered Design at Merck: How One IT Organization Became More Entrepreneurial and Enhanced Its Role in the Process. *IBIMA Business Review*, 1–10. https://doi.org/10.5171/2017.395969

Jaskyte, K., & Liedtka, J. (2022). Design thinking for innovation: Practices and intermediate outcomes. *Nonprofit Management and Leadership*, *32*(4), 555–575. https://doi.org/10.1002/nml.21498

Knight, E., Daymond, J., & Paroutis, S. (2020). Design-Led Strategy: How To Bring Design Thinking Into The Art of Strategic Management. *California Management Review*, *62*(2), 30–52. https://doi.org/10.1177/0008125619897594

Lager, T., & Fundin, A. (2022). Deployment of innovation methodologies as supporting instruments for the product innovation process in the process industries. *International Journal of Innovation Management*, *26*(7). https://doi.org/10.1142/S1363919622500578

Lahiri, A., Cormican, K., & Sampaio, S. (2021). Design thinking: From products to projects. *Procedia Computer Science*, *181*, 141–148. https://doi.org/10.1016/j.procs.2021.01.114

Lee, H., Zhang, Y., Zhang, H., & Liu, X. (2023). Challenges and opportunities of utilizing design thinking in the industry 4.0 era: based on the case study of industry wastewater treatment system development project process. *Journal of Innovation and Entrepreneurship*, *12*(1). https://doi.org/10.1186/s13731-023-00315-x

Liedtka, J. (2015). Perspective: Linking Design Thinking with Innovation Outcomes through Cognitive Bias Reduction. In *Journal of Product Innovation Management* (Vol. 32, Issue 6, pp. 925–938). https://doi.org/10.1111/jpim.12163

Malynovska, G., Mosora, L., Kis, S., Topolnytska, T., & Kalambet, Y. (2021). Design Thinking Method Implementation in Personnel Certification Procedures. *European Integration Studies*, *1*(15), 22–33. https://doi.org/10.5755/j01.eis.1.15.29134

March, J. G. (1991). *Exploration and Exploitation in Organizational Learning* (Vol. 2, Issue 1). https://www.jstor.org/stable/2634940?seq=1&cid=pdf-

Matthews, B., Doherty, S., Worthy, P., & Reid, J. (2023). Design thinking, wicked problems and institutioning change: a case study. *CoDesign*, *19*(3), 177–193. https://doi.org/10.1080/15710882.2022.2034885

Mehta, S., & McCay, J. (2015). Designing Personal Protective Equipment for Pesticide Applicators in India Using a Human-Centered Design Approach. *Environmental Research*, *142*, 34–45. https://doi.org/https://doi.org/10.31274/itaa.17064

Meinel, M., Eismann, T. T., Baccarella, C. V., Fixson, S. K., & Voigt, K.-I. (2020). Does applying design thinking result in better new product concepts than a traditional innovation approach? An experimental comparison study. *European Management Journal*, *38*(4), 661–671. https://doi.org/10.1016/j.emj.2020.02.002

Micheli, P., Wilner, S. J. S., Bhatti, S. H., Mura, M., & Beverland, M. B. (2019). Doing Design Thinking: Conceptual Review, Synthesis, and Research Agenda. *Journal of Product Innovation Management*, *36*(2), 124–148. https://doi.org/10.1111/jpim.12466

Mikkelsen, J. B., & Lange, I. S. G. (2017). Place in transition: Exploring the potentials of relocating disused oil rigs and transforming them into public places. *Journal of Landscape Architecture*, *12*(2), 74–84. https://doi.org/10.1080/18626033.2017.1361095

Mononen, L. (2017). Systems thinking and its contribution to understanding future designer thinking. *Design Journal*, *20*(sup1), S4529–S4538. https://doi.org/10.1080/14606925.2017.1352949

Nagaraj, V., Berente, N., Lyytinen, K., & Gaskin, J. (2020). Team Design Thinking, Product Innovativeness, and the Moderating Role of Problem Unfamiliarity. *Journal of Product Innovation Management*, *37*(4), 297–323. https://doi.org/10.1111/jpim.12528

Nakata, C., & Hwang, J. (2020). Design thinking for innovation: Composition, consequence, and contingency. *Journal of Business Research*, *118*, 117–128. https://doi.org/10.1016/j.jbusres.2020.06.038

National science and technology council. (2023). *Sustainable chemistry report - Framing the federal landscape*.

Nielsen, S. L., Christensen, P. R., & Storvang, P. (2021). Does Design Thinking Benefit Ambidextrous Dynamics between SME Managers' Entrepreneurial and Administrative Mindsets? *Design Journal*, *24*(5), 1–21. https://doi.org/10.1080/14606925.2021.1959121

O'Reilly, C. A., & Tushman, M. L. (2004, April). The Ambidextrous Organization. *Harvard Business Review*.

Piwowar-Sulej, K. (2020). Design thinking. Istota koncepcji oraz możliwości jej zastosowania w przemyśle chemicznym. *PRZEMYSŁ CHEMICZNY*, *1*(3), 124–127. https://doi.org/10.15199/62.2020.3.16

Quaiser, R. M., & Pandey, S. K. (2023). Design thinking enabling innovation: a literature review. *Innovation: The European Journal of Social Science Research*. https://doi.org/10.1080/13511610.2023.2238910

Randhawa, K., Nikolova, N., Ahuja, S., & Schweitzer, J. (2021). Design thinking implementation for innovation: An organization's journey to ambidexterity. *Journal of Product Innovation Management*, *38*(6), 668–700. https://doi.org/10.1111/jpim.12599

Rösch, N., Tiberius, V., & Kraus, S. (2023). Design thinking for innovation: context factors, process, and outcomes. *European Journal of Innovation Management*, *26*(7), 160–176. https://doi.org/10.1108/EJIM-03-2022-0164

Roth, K., Globocnik, D., Rau, C., & Neyer, A. K. (2020). Living up to the expectations: The effect of design thinking on project success. *Creativity and Innovation Management*, *29*(4), 667–684. https://doi.org/10.1111/caim.12408

Santa-Maria, T., Vermeulen, W. J. V., & Baumgartner, R. J. (2022). The Circular Sprint: Circular business model innovation through design thinking. *Journal of Cleaner Production*, *362*. https://doi.org/10.1016/j.jclepro.2022.132323

Santos, A. B. A. dos, Bianchi, C. G., & Borini, F. M. (2018). Open Innovation and Cocreation in the Development of New Products: the role of design thinking. *International Journal of Innovation*, *6*(2), 112–123. https://doi.org/10.5585/iji.v6i2.203

Schniederjans, D. G., & Khalajhedayati, M. (2023). Corporate Responsibility Communication and Score Trends: A Buyer and Supplier Perspective. *International Journal of Production Economics*, *257*. https://doi.org/10.1016/j.ijpe.2023.108780

Shapira, H., Ketchie, A., & Nehe, M. (2017). The integration of Design Thinking and Strategic Sustainable Development. *Journal of Cleaner Production*, *140*, 277–287. https://doi.org/10.1016/j.jclepro.2015.10.092

Sinan Erzurumlu, S., & Erzurumlu, Y. O. (2015). Sustainable mining development with community using design thinking and multi-criteria decision analysis. *Resources Policy*, *46*, 6–14. https://doi.org/10.1016/j.resourpol.2014.10.001

Statista research department. (2023, October 4). *2023 ranking of the global leading chemical companies based on revenue*.

Tidd, J., & Bessant, J. R. (2020). *Managing innovation* (7th ed.). John Wiley & Sons Inc.

United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development*.

Vignoli, M., Dosi, C., & Balboni, B. (2023). Design thinking mindset: scale development and validation. *Studies in Higher Education*, *48*(6), 926–940. https://doi.org/10.1080/03075079.2023.2172566

Waerder, B., Stinnes, S., & Erdenberger, O. (2017). Design thinking as driver for innovation in the chemical industry. *Journal of Business Chemistry*, *14*(2), 41–50.

Waidelich, L., Richter, A., Kölmel, B., & Bulander, R. (2018). Design Thinking process model review. *IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)*.

Watterson, J. L., August, A., Fourt, J., & Brettler, T. (2022). The Role of Human-Centered Design in Insulin Pen Innovation and the Future of Insulin Delivery. *Journal of Diabetes Science and Technology*, *16*(3), 623–627. https://doi.org/10.1177/19322968211043921

Wilson, G. T., Clark, N., Hatton, F. L., Trimingham, R., & Woolley, E. (2022). Perpetual plastic for food to go: a design-led approach to polymer research. *Polymer International*, *71*(12), 1370–1375. https://doi.org/10.1002/pi.6401

Yorgun, I., Egel, R., Lamers, L., & Kuhlenkötter, B. (2023). An approach inspired by Design Thinking methodologies to improve the company-wide collaboration applied in a Hydrogen Electrolyzer project. *Procedia CIRP*, *119*, 1097–1102. https://doi.org/10.1016/j.procir.2023.02.182

Yuhun, P., Roenthon, H., Laitrakull, K., Boonmeelapprasert, C., & Tungthansamma, D. (2023, October 2). Modernize Execution Phase of Drilling Process in Offshore Brownfield (Gulf of Thailand) to an Overlapped Environment Using Digital Solution. *ADIPEC - Day 1 Mon, October 02, 2023*. https://doi.org/10.2118/216167-MS

Zheng, D. L. (2018). Design thinking is ambidextrous. *Management Decision*, *56*(4), 736–756. https://doi.org/10.1108/MD-04-2017-0295