A framework to identify applications for a technical innovation

Case study: A pressure-activated, colour-changing and flexible material

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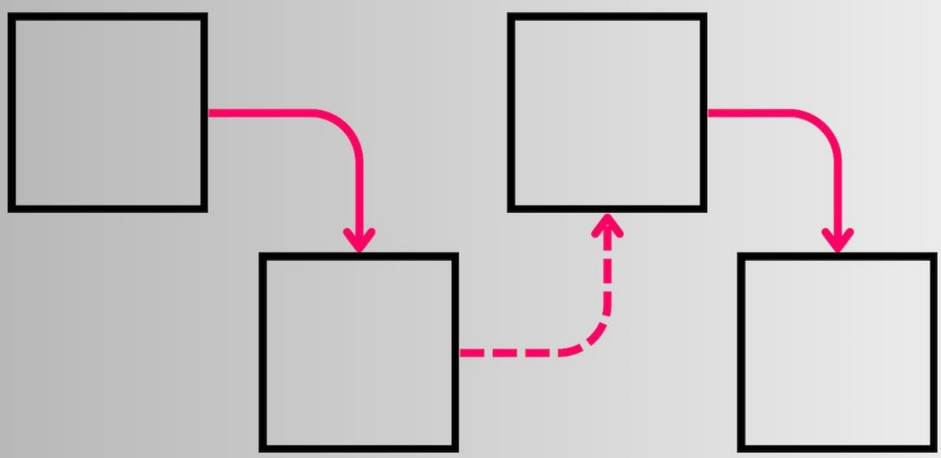

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Preface

From the outset, I have been interested in the link between engineering and management. Growing up with a mother with a background in technology and a father with a background in the management field, I am not only drawn to this link but embody it. It was difficult to choose between the two paths and hence I pursued both in my two master's degrees. However, the idea that I had to make a choice evolved into a realisation that my journey is inherently intertwined with both. And with this master thesis, I have been able to make an imprint on both research fields.

My thesis adventure began at the BITE (Bio-Inspired Technology) group at the TU Delft, where I created a material that reflects the magical colour change of the octopus. A valuable application - helping lymphedema patients gain control over their treatment and time - served as a guiding principle for the design. The thought persisted that with this innovative material, more could be possible.

My thesis adventure concludes at TU Delft's section of ETI (Economics of Technology and Innovation), where I was able to complete the circle of my narrative. Technical inventions often have an initial purpose, sometimes come about by chance, but I recognised that inventions often can address multiple problems. Yet, amidst this exploration, I uncovered a notable absence of clear guidelines for identifying such problems, and therewith maximising the impact of such innovations. These guidelines would be very useful for inventors and technical business managers to extract more value from one invention. Motivated by the relevance, I enthusiastically embarked on this challenge of delineating these guidelines within this master thesis.

In the second half of my journey, I once again greatly valued the support of various people. First and foremost, I would like to express my gratitude to my first supervisor, Roland Ortt. I characterise the core values of our meetings as positive, clear and educational. Thanks to your encouragement, I was able to maintain the pace at which this thesis progressed, for which I am very grateful! Additionally, I would like to thank Udo Pesch for his role as the second supervisor. At pivotal junctures of this thesis journey, you brought an insightful perspective and feedback that I found very valuable! Finally, I would like to thank my mom, dad and my sister, my friends and Christiaan for their support throughout the thesis journey.

The second and final half has been played. While this game has reached its conclusion, new adventures will follow, which I am eagerly anticipating.

Loulou Koudstaal,
April 2024, Delft

"If the only tool you have is a hammer, you tend to see every problem as a nail." – Abraham Maslow

Executive summary

Background. The curriculum of an engineering education involves a systematic approach for problem-solving. A problem is defined, often leading to multiple design requirements, which are then incorporated into a technical product along with the constraints imposed by these requirements. The substantive actions within these steps require knowledge and creativity, but the systematic approach is helpful with providing direction. This systematic approach was conducted prior to this research within the master thesis of Biomechanical Design. Here, an innovative flexible material design was presented that changes colour under a specific amount of pressure. This technical innovation was developed for patients with lymphedema such that they gain control over their time and treatment due to self-administering the manual lymphatic drainage massage. The effectiveness of this massage lies in the amount of pressure. Hence, we presented a colour-changing device that helps indicate the correct amount of pressure. While direction was provided for this research, engineering students are not given direction on how to go from a technical innovation to potential problem applications that can increase the value of a technical innovation. An innovation may transcend its original intent and be useful in multiple contexts. This form of innovation is also highly relevant for business managers to increase profits by exploiting their technical products and therewith expanding their market share.

Problem. Despite its apparent relevance in the engineering and business field, the literature is limited in terms of systematic problem-finding processes, while there exists an abundance of solution-finding processes. Identifying alternative applications for a technical innovation thus represents a gap in the literature. Filling this gap by providing direction to a problem-finding process therefore holds scientific relevance in addition to the managerial relevance. By shifting the focus from problem-solving to problem-finding for a versatile technical solution, this thesis aims to uncover a systematic problem-finding process that can be used to identify alternative applications and validate this process by applying it to the case study, which is the flexible pressure-activated and colour-changing sheet as design in the Biomechanical Design thesis. This objective resulted in the main research question of this study: “How to identify alternative applications for a technical innovation?”

Research approach. The literature on problem-finding techniques is next to scarce, also dispersed and unconnected. Therefore broad methods within the literature where examined whether they could contribute to a comprehensive process or not, stating subquestion 1: “Which methods within the literature contribute to the research field of identifying alternative applications based on a technical innovation?”. To ultimately establish a comprehensive overview of potential tools and methods that can aid in the identification of applications, a unique literature review approach was employed. In a preliminary research phase, 5 relevant articles emerged as reference articles for subsequent steps. However, in the systematic search, we did not retrieve these reference articles using an accurate search term. A novelty in this systematic search was the tailoring of this accurate search term with found key terms. Although this yielded multiple results, it lacked a significant variety of techniques. To uncover this variety or uncover its absence, we used the AI tool ResearchRabbit to conduct a scoping search. This resulted in a greater variety of additional techniques, although it is still concluded that the literature on systematic problem-finding processes is scarce, disperse and unconnected.

Research findings. The aim of this study is to provide a comprehensive process that can be applied in the search for alternative applications for a technical innovation. To achieve this, the possibility of connecting the identified tools and methods was explored, as indicated by subquestion 2: “How do the problem-finding methods found in the literature compare to each other?”. To establish connections, individual article groups were first examined: TRIZ (theory of inventive problem solving), Cognitive, Roadmapping and Patent Analysis. The first three groups primarily encompass

qualitative methods, while the last group contains quantitative methods. From the TRIZ, Cognitive, and Patent Analysis groups, an overarching process of 4 steps was identified, although different types of approaches were proposed for each step within the groups. The overarching process follows the sequence of define, generalise, link and choose, namely: (1) Define the technology characteristics, (2) Generalise the function of the technology, (3) Link the generalised functions to abstract problem applications, and (4) Choose an application. All the proposed approaches per step were analysed, and multiple approaches of different steps were applied to the case study, yielding insights into the requirements for implementing the respective technique, the type of results after execution, and their cumbersomeness.

Analysis. These insights drawn from the execution of various approaches were used to draw connections between different proposed tools and methods within the literature, resulting in a framework that offers a multitude of paths to traverse the 4 defined steps, thereby depicting different problem-finding processes. From this framework, three main processes can be distinguished: the qualitative process, the quantitative process, and the management process.

The first main process involves conducting a Subject-Action-Object (SAO) analysis and a morphological analysis, followed by using the obtained information in a guided brainstorm session. A scoring method facilitates the selection of a promising application. This first main process can be entirely qualitative and has been applied to the case study, particularly suitable for similar situation where resources are limited, e.g. in Small and Medium-sized Enterprises (SMEs). The results, i.e. the alternative applications, for the case study were for example to use the material as a label to prevent counterfeit sales, to monitor pressure of a bandage and apply appropriate pressure points during massage therapies. The latter resembles the initial purpose of this technical design, which shows a validation of this process. However, the depth of the application, meaning the fact that it could be used for the manual lymphatic drainage massage, is limited.

Where the qualitative process is recommended for engineers and SMEs, the quantitative process is a better fit for firms capable of making significant investments. This process analyses a set of patents using an algorithm. However, the requirement for a well-labeled patent set makes this approach challenging, and implementing an algorithm makes it cumbersome.

For management teams interested in innovation but not necessarily seeking alternative applications for their technology, yet open to exploring such possibilities, the methods called Scenario Field Analysis (SFA) or Quality Function Deployment (QFD) are recommended. These can be combined with either a portfolio analysis or prioritising a technology domain.

While these recommended main processes serve as guidelines, the framework allows for deviation.

Extra factor of influence. One notion that should be made is that during the execution of the guided brainstorm process described in the qualitative main process, the Artificial Intelligence (AI) tool ChatGPT3.5 was used as a “creative collaborator”. This led to an acceleration in diverging towards alternative applications and an increase in creativity, especially as we maintained a critical engineering perspective. Through this implementation of the guided brainstorm, there was a though that AI can have a significant impact on the established framework. Upon researching this, it was found that there are several challenges and risks associated with using AI in conjunction with brainstorming or patent analysis. When conducting a brainstorm with AI, most challenges can be overcome through critical thinking and guiding the brainstorm, as an expert can uncover misleading information and will not violate authorship rights. However, when conducting patent analysis with AI, risks arise from for example unknown biases and reliability issues as the AI is a black box. Next to this, AI performs currently improper image analysis from patents. These challenges are more difficult to address, and it is therefore not recommended to use AI in the framework for the quantitative approaches. The conclusion is that AI in qualitative approaches, that are intended for divergence, such as in steps 2 and 3, will enhance results when critical thinking is maintained. This presents opportunities for engineers and SMEs, as opposed to relying solely on human experts, they can now leverage AI, which essentially functions as a multitude of experts.

Evaluation. This study emerged from a designed colour-changing material and the desire to find alternative promising applications for it. A problem arose in the literature regarding problem-finding methods. This study introduced therefore innovative aspects within the literature review, which is applicable to a situation wherein articles on a particular subject are scarce, dispersed and unconnected. Changes were made within the preliminary, systematic, and scoping steps to arrive at a collection of articles that depict the literature landscape of problem-finding methods. An additional systematic search was required, wherein a tailored search term included additional key terms, and ResearchRabbit was used in the scoping phase. Ultimately, from the processed findings from the literature, a framework is provided to assist engineers, both large and small firms, in navigating the process of identifying alternative applications for a given technology. Additionally, insights are offered regarding the use of AI in conjunction with this framework. Previously, various problem-finding techniques and methods have not been presented alongside each other, and therefore also not been connected with each other. Therefore, this research holds scientific relevance. This result of this study, i.e. the conceived framework, is guiding business managers in a problem-finding process and facilitating the increasement of the value of a technical innovation, making this research managerial relevant as well.

Future research. By aiming to establish a generic process and applying it to the case study, the depth of this research primarily lies in qualitative methods and is thus limited in quantitative approaches. Consequently, the quantitative approaches remain unvalidated. The qualitative approaches include validations based on a single case study and on the various technologies discussed in the respective article of the techniques. To establish a reliable framework, multiple validations will need to be conducted. Furthermore, this study did not clearly differentiate between technologies that start with an initial application and those that have no application yet, and whether this influences the paths one can follow within the framework.

Therefore, it is important to critically examine the framework. Further validations have to be conducted, and it is essential to monitor the advancements of AI in patent analysis to make necessary refinements to the framework if possible.

Conclusion. This study presents the development of a framework designed to serve as a guideline for entities seeking alternative problem applications for their technical innovations, thereby possibly enhancing the value of these innovations. This framework serves as the answer to the main question "How to identify alternative applications for a technical innovation?".

Abbreviations

Abbreviation	Definition
ARM	Association Rule Mining
ATA	Alternative Technological Applications
BMD	Biomechanical Design
CAD	Computer-aided Design
EPA	Evolution Potential Analysis
ETP	Existing technologies and products
FA	Functional Analysis
IFOS	Inverse Function Oriented Search
MLD	Manual Lymphatic Drainage
MOT	Management of Technology
MPV	Main Parameter Value
PPA	Product platform analysis
PTET	Patient Training Education Tool
QFD	Quality Function Deployment
ROI	Return of Investment
SAO	Subject-Action-Object
SFA	Scenario Field Analysis
SIP	Systematic Innovation Process
SME	Small- and Medium Enterprise
TDF	Technology Description Framework
TOA	Technology Opportunity Analysis
TOD	Technology Opportunity Discovery
TRIZ	Teoriya Resheniya Izobretatelskikh Zadatch (Theory of Inventive Problem Solving)
VOC	Voice of Customer

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A thesis submitted to Delft University of Technology
in partial fulfilment of the requirements for the degree of

Master of Science

in Management of Technology

Faculty of Technology, Policy and Management

by

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To be defended publicly on Friday May 3, 2024 at 10:00AM

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Project duration:	November 20, 2023 – May 3, 2024	
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An electronic version of this thesis is available at http://repository.tudelft.nl/ .

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Contents

1 Introduction

This chapter introduces a master thesis study that builds upon a biomechanical thesis research conducted previously. During this biomechanical research, a problem was encountered that necessitated a more comprehensive explanation: thinking of a promising application for a technical innovation is not something that happens spontaneously unless one relies on luck. Given that the management of firms, as well as engineers themselves, are reluctant to let profits hinge on chance, this emerging research is of great importance, because it undertakes the challenge of systematically identifying the most promising applications for a particular technology. The technology conceived during the biomechanical research will be used as case study to test the devised approach. This chapter elucidates on the technical innovation and its purpose from an engineering perspective, the problem that was encountered, and the setup of this thesis through the formulation of research questions. Additionally, the scope of the study is established, and the relevance is mentioned.

1.1. Prior research

This research builds on the master thesis of biomechanical design whereby a pressure-activated, colour-changing and flexible material is designed for aiding lymphedema patients in performing the Manual Lymphatic Drainage (MLD) massage. Lymphedema is a chronic condition characterised by the accumulation of fluid in the tissues in the limbs, resulting in pain, discomfort, reduced motion, fatigue, and body image issues. The MLD massage addresses the impaired lymphatic flow by manually redirecting the accumulated fluid to healthy lymphatic pathways by using a dragging and squeezing motion [6-11]. The most challenging part of performing MLD massage is that excessive pressure can cause increased swelling and damage to the sensitive skin and remaining lymph nodes, impeding the effectiveness of the treatment and potentially causing further complications. Although, insufficient pressure is not stimulating the lymphatic flow. This therapy is therefore performed by a trained therapist to ensure safety and efficacy. The MLD has to be administered with a consistency of 4-5 times a week, 20-40 minutes per treatment [12, 13]. To alleviate the workload for the healthcare system, and provide the patient a sense of empowerment and control over their treatment and time, this pressure-activated colour-changing sheet takes the form of a patient training education tool (PTET). This tool offers the patients the option to apply the MLD themselves, resulting in a sense of freedom over their time and treatment. The PTET is a pliable and slim sheet that easily adapts to the contours of the limb. Exerting manual pressure onto this sheet induces a colour change at a specific pressure threshold, giving the lymphedema patients a visual sign they have reached the required amount of pressure.

The material, depicted in Figure 1, works as a colourimetric pressure sensor that does not make use of electronic pressure sensors, but fully functions only using the materials: silicone (Ecoflex 00-20), pigments, PP0.075 (Polypropylene) and optional LDPE0.05 (Low Density Poly Ethylene). This makes the material hygienic for safe use as it is washable.

Figure 1: A photo of the prototype of a pressure-activated colour-changing and flexible material

1.2. Problem statement

In the master thesis of Biomechanical Design (BMD) an innovative design is presented, in the form of a PTET, for a colour-changing sheet. In the course of a thorough research into colour-changing flexible materials, characterised by a colour activation through pressure, such a design has not been found. Although the purpose of this sheet is promising, and was needed in the process to achieve this design, an innovation can transcend its original intent, revealing unexpected applications and potentials. This master thesis for Management of Technology (MOT) seeks to explore more possibilities for this inventive solution. The research in this master thesis completes the circle when examining the shift from a problem-first approach as seen in BMD research to a solution-first approach as will be executed in this MOT study, see Figure 2. Interestingly, while there are numerous solution-finding methods, the literature is limited in its approach to problem-finding methods. Identifying diverse applications for a technical innovation represents a gap. It is worth acknowledging, this type of research is particularly crucial in bioinspired design research, where there is often research done in mimicking nature's smart mechanisms, yet in some cases without addressing a specific problem application [3, 14, 15]. Typically, and also in prior BMD thesis, a logical application is chosen that follows from the biological mechanism, perhaps in a flash of genius as mentioned by Sheu & Lee [4]. This is done to establish requirements and create a design, but such intelligent biological systems could contribute much more in terms of solving problems. It is a matter of finding these problems, which is often a challenge for engineers who are so deep-rooted in problem-finding approaches [3, 14, 15].

Next to this, the identification of the by Bianchi et al. [2] termed Alternative Technological Applications (ATAs) often poses a challenge in small- and medium enterprises (SME) that want to exploit their technology. This is due to the cognitive limitations and the absence of a multidisciplinary mindset of most individuals involved with developing high-tech innovations. Recognising these challenges, Bianchi et al. [2] proposed a structured and systematic methodology tailored for SMEs to

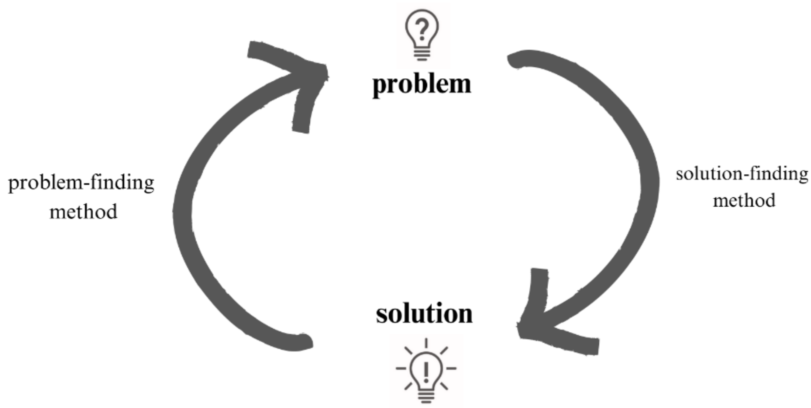


Figure 2: The cyclic procedure of shifting from a problem-first approach to a solution-first approach that shows the change in methods used in both theses (BMD and MOT)

identify ATAs. This approach integrates components of TRIZ (Theory of Inventive Problem Solving) with a ranking technique and portfolio management tools. Drawing upon an illustrative case of an Italian SME packaging firm, the authors demonstrate the application of their method. However, no other systematic step-by-step approaches to finding applications to a technical innovation were found in an exploratory search besides Bianchi et al.'s article [2]. Thus, there exists a significant gap in the literature concerning generic systematic step-by-step approaches to identify alternative applications for a technological invention.

The goal of this study is to identify and understand potential applications and thereby opportunities next to the intended functionality of a technical invention. This study holds therefore managerial significance as it can increase a firm's value by increasing a technology's value. Addressing the limited problem-finding methodologies is of scientific relevance due to its potential filling a gap.
By shifting the focus from problem-solving to problem-finding for a versatile solution, this thesis aims to uncover alternative applications for the colour-changing sheet as is presented in the BMD thesis and provide validation to the found systematic approach.

1.3. Research objective & questions

The objective of this study is to establish a structured method for identifying promising applications based on a technical innovation, i.e. identifying problems for a particular solution, as described in Section 1.2. In this thesis, a technical innovation refers to a technological principle that can provide a functionality and is composed of a set of subsystems. Within a specific context, a customer group may perceive a need for this functionality, which could potentially lead to the application of the innovation. This need for a functionality felt by a customer group in a specific context is the definition of an application. The generic problem of this study is shaped by the identification of alternative applications, which is encapsulated in the main research question: 'How to identify alternative applications for a technical innovation?'. To validate the method, the colour-changing material, i.e. technical innovation, designed during the master thesis program BMD is used as a case study.

RQ

How to identify alternative applications for a technical innovation?

Using the RQ, the sub-questions (SQ) will be defined. As outlined in Section 1.2, it becomes evident that the literature on problem-finding methods is sparse or elusive. A first important step is therefore to examine the nature of this literature and ascertain whether a framework can be derived from the existing literature. A comprehensive literature review will form the foundation of this research. The methods that appear in the literature as relevant for finding alternative applications for a technical innovation will be listed. This constitutes SQ 1: 'Which methods within the literature contribute to the research field of identifying alternative applications based on a technical innovation?'. Subsequently, the processes proposed in the literature need to be dissected, examining how these processes relate to each other and where they can complement each other. This information is encompassed by SQ 2: 'How do the problem-finding methods found in the literature compare to each other?'. Based on this information, a framework can be developed to serve as an answer to the main question.

SQ 1

Which methods within the literature contribute to the research field of identifying alternative applications based on a technical innovation?

SQ 2

How do the problem-finding methods found in the literature compare to each other?

1.4. Scope of research

This research will generate an overview based on identified elements from the problem-finding literature, thereby establishing a framework equipped with a systematic plan for identifying alternative applications for a technical innovation. This research will focus on the pressure-activated, colour-changing sheet as a case study. Also, this process has potential to be applicable across various technical fields, wherefore the generalisability of this study will be discussed.

1.5. Research relevance

The MOT study focuses on stimulating curiosity towards discovering products and services that will enhance customer satisfaction, corporate productivity, profitability, and competitiveness. This can lead to research related to strategies, knowledge processes, research and product development, and innovation within a firm. This work contributes to all these aspects of MOT as this research result, i.e. a framework that will generate alternative applications for a technical invention, improves strategies and arouses innovations within large and small businesses. This research's contribution is therefore bringing new insights within the MOT curriculum in the form of an established methodology that is able to identify alternative applications for a technical innovation.

The theoretical perspective explains the scientific relevance of the research. The first explorative study of this research revealed a general scarcity of well-described and tested methods to define applications for a technical innovation. One idea was found, the ZIRT or reversed TRIZ method, as articulated by Bianchi et al. [2] and Souchkov [16]. Yet this method was not well-defined, widely applied or tested. Such a method that is able to define applications, is proposed as a means to identify multiple problems from a specific solution, thereby extracting enhanced value from a given invention. Through employing as case study the pressure-activated colour-changing material we aim to clarify the complexities of such an approach. This could involve the ZIRT method, or alternatively, a method devised through the combination or variation of various approaches documented in the extensive literature review.

From a managerial perspective, it would be intriguing to research the forms of business innovation to enhance profitability or increase a technical invention's social impact. One category of business innovation is value proposition innovation, involving modifications or additions to the innovation to eventually improve the existing one. This could entail incorporating technological enhancements or applying the innovation to different markets. Strategically implementing an innovation across diverse technical domains can increase its potential [16]. It has thus been demonstrated that exploring alternative technical domains can increase the invention's value. However, as outlined in Section 1.2, the challenge lies in delineating potential applications rather than in the standard market analysis determining the success or failure of the product. For technology firms, and therefore the technology managers, this perspective can provide insights and bring promising opportunities associated with outsourcing their technology. In navigating the challenges inherent in leading a business, such a method can significantly mitigate risks by broaden the horizons of a product and increasing profits.

The discovery of a handbook or guidelines to systematically identify promising applications for a technical innovation holds scientific significance as well as managerial importance. This is applicable not only within a specified research field but across all research domains.

1.6. Thesis structure

To achieve the stated objective of this study, a meticulous approach is undertaken, beginning with an extensive literature review outlined in Chapter 2. Subsequently, the findings are provided in Chapter 3, the literature synthesis, where also the initial concluding remarks on these findings are discussed. Chapter 4 begins the quest for a framework by analysing the four found steps of the process of identifying alternative processes. Chapter 5 adds the information obtained from the previous chapter and presents the final framework along with its functioning. Chapter 6 will provide an additional insight into the overall narrative by discussing the integration of Artificial Intelligence (AI) within the problem-finding framework and the challenges associated with it. Hereafter a discussion is held about the study's observations, recommendations are given and conclusions are drawn in respectively Chapter 7 and Chapter 8.

The progression of this research is depicted as a pyramid in Figure 3 as each step of this study builds onto the next step. The base is formed by a thorough literature research that gathers relevant articles to achieve this study's objective, i.e. a problem-finding framework usable for managers and engineers. The grey part of the pyramid indicates how the literature processing unfolded. Initially, the relevant articles are categorised into main groups, from which relevant information for the framework is filtered. A four-step methodology is eventually chosen as the generic method. However, each step has several options for execution. The steps and these options per step are analysed. Finally, the framework is established. Then, a critical examination is necessary to explain what is still needed to arrive at the final validated framework. It is also noted that emerging AI technology impacts the framework. The top of the pyramid, which is an empty box at the moment, represents the step of applying the renewed information obtained from the previous layer.

Note that one will always remain active at multiple levels. In level 4 the framework needs to be subjected to current technologies and insights. At level 0 the amount of relevant literature increases, leading to new possibilities in the four-step methodology analysed in level 2. Nevertheless, it is expected that the four defined steps will remain the same, and only the number of possibilities will be adjusted. Through newly found possibilities a more comprehensive framework at level 3 will be established. This study encompasses levels 0 through 4 of the pyramid. In Chapter 2 the literature research of level 0 starts.

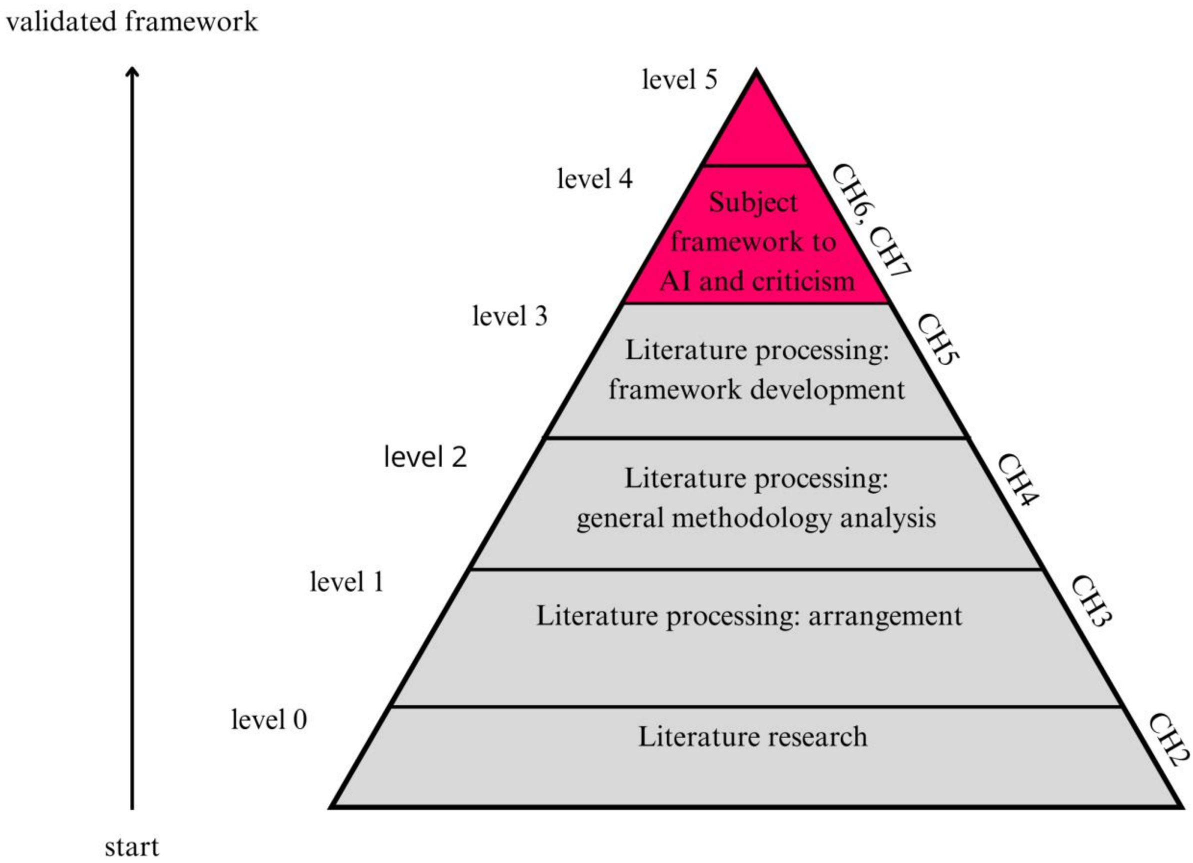


Figure 3: The progression of this research represented in a pyramid form. Level 0 through 3 comprise the literature research and processing indicated by grey boxes. Level 4 and 5 require a bird's eye view of the defined framework to keep it up-to-date and future proof.

2

Literature review: search strategy and process

A literature review is vital for extracting a potential knowledge gap and analysis of the existing scientific knowledge. The aim of this literature review is to see whether there are methods capable of deducing applications from a proposed technical innovation, and if so to categorise the devised methods in such a way that final decision on which methods to use in this study is elucidated based on this categorisation. This should answer SQ1 as stated in Section 1.3. This literature review consisted of multiple search strategies: preliminary research, systematic research and scoping research. On each of these strategies is elaborated on in respectively Section 2.1, Section 2.2 and Section 2.3. Through these sections the process of this literature research will be delineated, clarifying that this research will transition from a systematic to a scopic research. At last, a concluding view will be given on this literature process in Section 2.4.

2.1. Preliminary research

2.1.1. Approach

Initially, an exploratory stance was adopted during a preliminary literature research. Multiple terms were used in the Google scholar and Scopus databases. Search strings were constructed from various keywords and their synonyms found using Thesaurus. Keywords included, among others, innovation, method, application, technological, and identify. Subsequently, terms identified within crucial articles, such as technology exploitation, application exploration, and technology opportunity, were further investigated. In this phase of the literature research, an article with a significant title is immediately saved, examined, and may be used for snowballing. The number of relevant articles found per search term is irrelevant at this stage. The objective of this search is to gain a comprehensive understanding of the topic and identify key terms that play a role, which can then be employed during a systematic literature research.

Ultimately, the decision was made to consider five articles as relevant, given that these articles present a preliminary delineation among various methods that could identify applications using technical innovations. These articles encompass a systematic method using TRIZ elements (in reverse) tailored for SMEs, a method integral to a systematic innovation process (SIP) termed application exploration, and approaches employing patent and scientific paper data. These articles already indicate a dichotomy between qualitative and quantitative approaches. The insights derived from these identified articles will be used for the validation of the systematic literature search.

The following five articles were considered as primary articles from preliminary research:

1. “Enabling open innovation in small- and medium-sized enterprises: how to find alternative application for your technologies.” by Bianchi et al. [2]
2. “A proposed process for systematic innovation.” by Sheu and Lee. [4]

3. “Systematic business innovation: a roadmap.” by Souchkov. [16]
4. “Technology opportunity discovery (TOD) from existing technologies and products: A function-based TOD framework.” by Yoon et al. [17]
5. “Identifying technology opportunity using SAO semantic mining and outlier detection method: A case of triboelectric nanogenerator technology.” by Li et al. [18]

2.1.2. Summary of primary articles

In the possession of an innovative technology, one could opt for a greater potential from a business perspective than merely using the technology for its intended function. For instance, small- and medium-sized enterprises (SMEs) can benefit from out-licensing their technology. Through this strategic approach, they can enhance their economic gains without the need to build or acquire new assets, particularly as SMEs typically have finite resources. The commercial exploitation of a product aligns with the practice of Open Innovation, fostering accelerated innovation by facilitating increased knowledge streams. However, a challenging aspect of this strategy lies in the identification of Alternative Technology Applications (ATA). This challenge is primarily attributed to cognitive limitations and a lack of multidisciplinary expertise [2]. Consequently, research is focused on developing the optimal process for systematically searching for viable alternative applications for a certain technology.

The identification of potential applications for a technology can be considered a part of the innovation process. Sheu and Lee [4] view this alternative application identification as integral to a Systematic Innovation Process (SIP). In this phase, the focus is on business opportunity identification, followed by an examination of whether the technology can be cross-industry applied and thereby exploited. They delineate three possible approaches to innovation: (1) a flash of genius, (2) empiric path, and (3) methodical path. A flash of genius refers to an immediate and insightful innovation. The empiric path involves the thought process during brainstorming or trial-and-error process, which, like a flash of genius, often relies on luck. Therefore, Sheu and Lee [4] recommend following a methodical path, i.e., a systematic process, to ensure that outcomes are not dependent on luck and to guarantee innovative product development. Within their proposed SIP, they offer TRIZ and non-TRIZ tools.

For application exploration, the following non-TRIZ tools are suggested: Voice Of the Customer/Quality Function Deployment (VOC/QFD), product platform analysis (PPA), and Product/Technology roadmap. On the contrary, Bianchi et al. [2] introduced an inverse TRIZ method, using TRIZ tools in a unique manner. Similarly, Souchkov [16] introduced “ZIRT” or inverse TRIZ as a potential method to discover new areas for an existing technology, thereby fostering business innovation. TRIZ is a Russian acronym for ‘Teoriya Resheniya Izobretatelskikh Zadath’, translating to the ‘Theory of Inventive Problem Solving’. It is a conventional method for finding solutions to technical problems. In an inverse TRIZ method, the technical solution is already known, and the objective is to identify various problems it can address. At an abstract level, a similar technical problem often occurs in multiple technological fields at the same time, and correspondingly, the solution to this problem is largely similar [2].

The research progressed and current technical innovation systems are rapid and competitive. This is why identifying technological opportunities became a core task within the R&D teams of firms [17]. The early identification of opportunities is of paramount importance for governments and firms in their R&D efforts for strategically planning the innovation policies, ultimately aiming to achieve a first-mover advantage in the competitive market [18]. The goal is to discover and exploit technological opportunities ahead of the competition. This process is termed Technology Opportunity Discovery (TOD), representing the identification of opportunities that hold potential business value.

Explained

TRIZ

TRIZ stand in English for Theory of inventive problem solving and is a framework that is constructed after studying 40000 patents and their patterns. The standard procedure of the problem-solving framework is as follows: generalise a problem, find general solutions, find general problems, and develop a new specific solution. From the patent study 40 strategies are created to help with this concept generation [3].

Voice of the Customer (VOC)

The VOC is a customer-oriented approach that may find other applications for a certain technology that also helps the customer as it uses customer's desires [4].

Quality Function Deployment (QFD)

The QFD is a customer-oriented approach that helps to find customer requirements, and therewith find the functional requirements. These found requirements state the characteristics a new product should have. QFD is often the starting point for roadmapping [5].

Product platform analysis (PPA)

The PPA is a strategy that searches for derivative products and plans its diffusion [4].

Product/technology roadmap

Roadmapping entails outlining a plan for a product derivative over time and constructs a technology strategy on how the technology is used in this process [4, 5]

TOD can manifest in two types: predicting new technologies and products, or applying existing technologies and products (ETPs) [17].

Traditional methods for identifying technological opportunities include the Delphi method or the morphological analysis method. These methods are predominantly qualitative, relying on expert knowledge and experience. While expert judgment remains an important element in TOD, it is evident that experts are not infallible, and their reliability is often compromised by deviations and the inability to ensure repeatability. Additionally, there has been an increase in technical data and areas, driven by a rapid growth in big data. This has led to a lot more scientific papers and patents with a large amount of technical information. Consequently, sole reliance on expert judgment may no longer be sufficient. The methodologies have shifted from qualitative to quantitative analysis by leveraging objective data [17, 18].

Yoon et al. [17] proposes a function-based framework for TOD from a firm's ETPs. This framework relies on two steps: (1) a TOD knowledge base and (2) a TOD logic. The knowledge base is extracted from many patents from multiple technical fields and structures information on products, technologies and their functions. The logic element expresses the process of comparing the ETPs to other technologies or products using a stated semantic function. They used bibliographic and textual information of patents to provide input for decision makers. Others have used among others text-mining, citation network clustering, or keywords clustering to assess evolving trends and identify opportunities within [17, 18]. Some used visualisation methods, such as patent maps and vacuums and system evolution patterns.

Li et al. [18] extracted the Subject-Action-Object (SAO) structure from patents and scientific papers to find the semantic relationship. The S represents the technical solution, while the AO represents the function. This allows them to not only stay at the level of technical problems, but also focus on opportunities at the level of technical solutions. Next to this, they also use an outlier detection method to identify outlier points in scientific papers. Lastly, they make use of expert knowledge to validate their findings.

From this background narrative, drawn from 5 key articles, it is evident that there are differences in problem-finding methods at both qualitative and quantitative levels, as well as at systematic and creative levels. Based on this, a systematic literature research can be initiated with the required key terms.

2.2. Systematic research

To find relevant literature on application-finding or problem-finding methods the database Scopus was used. Based on the exploratory literature review and the first sub-question stated in Section 1.3, the following can be stated regarding what needs to be identified from literature using the appropriate terms: "We aim to find a method that takes an existing technical innovation as a starting point, allowing us to identify a technological opportunity in the form of alternative applications. Consequently, we intend to uncover a commercial gap for exploiting the existing technical innovation." In simpler terms, we are in search of a process that identifies alternative applications based on an existing technology. The fact that the research is based on an existing technology is very important to narrow down this search query as otherwise approximate 8700 results were found. Next to this, from the background information, it is evident that technology opportunity discovery can also involve predicting future products rather than applying existing products to something new. Given the emphasis of this study on the latter, it is imperative to include this aspect in the search term. The keywords derived from this process are used in the search query, as illustrated in Table 1.

Table 1: An overview of the components the proposed search string consists of

AND (across columns); OR (down rows)

Method	Find*	Alternative application*	Existing technology
Model	Deriv*	Alternative product*	Existing product*
Framework	Discover*	Potential application*	Existing technologies or product* (ETP*)
Approach Strategy	Develop* Identify*	Potential product* Promising alternative*	Existing mechanism* Existing (technolog*) device*
Process		Different application*	Existing (technolog*) innovation*
Analysis		Different product* Alternative technolog* Potential technolog*	

The summarising search term using Scopus would be:

TITLE-ABS-KEY((**method** OR model OR framework OR approach OR strategy OR process OR analysis) **AND** ((**find*** OR deriv* OR discover* OR develop* OR identify*) **W/1** ((**alternative W/1 application***) OR (alternative W/1 product*) OR (potential W/1 application*) OR (potential W/1 product*) OR (promising W/1 alternative*) OR (different W/1 application*) OR (different W/1 product*) OR "alternative technolog*" OR "potential technolog*")) **AND** ("**existing technolog***" OR (existing W/1 product*) OR (existing W/1 mechanism*) OR (existing W/1 device*) OR (existing W/1 innovation*)))

The structure of the search term is as follows. Initially, the key term ***method*** and its synonyms are incorporated. Subsequently, it is essential for the key terms ***find*** and ***alternative application***, along with their respective synonyms, to be juxtaposed in the text. If they are not juxtaposed, the word ***find*** would be a generic term and therefore irrelevant. This word is indeed crucial, as the focus is genuinely on finding alternative applications, not merely on alternative applications. Hence, the W/n syntax in Scopus has been employed, where the letter 'n' indicates the permissible number of words between the key terms, in this case, one word. The choice for n=1 was made after exploring various possibilities. W/0 yielded 18 results, of which 6 were deemed relevant after scanning the title and abstract. W/1 produced 33 results, with 7 articles considered relevant upon reviewing the title and abstract. W/2 resulted in 49 outcomes, with 7 relevant articles identified after examining the title and abstract. The initial 6 relevant articles were consistently present in each search, and only 1 additional relevant article emerged subsequently, even upon the expanding of the n-value. Consequently, the decision was made to set n=1. While it was possible to further increase the value of n, doing so would drastically diminish the number of relevant articles per retrieved result. This is because enlarging the value of n erodes the fundamental concept of using the W/n syntax, as the words would no longer be positioned at the correct distance from each other, potentially altering its contextual meaning.

The final component of the search term includes the key term ***existing technology*** and its synonyms. From the preliminary literature review, the term ***existing technology*** emerged as important, given the literature's focus on methods grounded in established technologies. Attempts were made to experiment with terms such as ***specific technology***. While this did indeed yield an increase in results, it did not translate into a corresponding increase in relevant findings. The same held true for phrases like ***current technology*** or ***new technology***. The inclusion of the term 'new' resulted in the retrieval of numerous methods related to new product development but failed to identify additional methods based on novel technologies. The usage of 'existing' appears to be the most appropriate approach in this context. Although one could argue that this imposes a limitation on the discovery of alternative methods, removing the word 'existing' from its key term led to an excessive surge in results (4677 to be precisely), rendering effective filtering unfeasible.

Another significant consideration in the search term is the use of an asterisk '*' to encompass multiple words at once, allowing, for example, the identification of 'derive' or 'deriving' through the inclusion of 'deriv*'. Furthermore, within the key term 'alternative application', the W/1 syntax is also employed, enabling the identification of phrases such as 'alternative technological applications'. Note that this syntax allows reference to something technological, although this may not be the case in all instances. In cases where the term 'technology' is already present, double apostrophes "…" are used, indicating that the term must appear in this specific sequence in the text. These symbols are not employed in situations with the W/n syntax, given the possibility of word inversion, as long as they appear adjacent with a maximum of one word in between.

As stated, this search term resulted in 33 documents, of which 7 were relevant after scanning the titles and abstracts. Despite the search term being tailored towards the identification of methodologies, only 3 articles proved to be relevant after subjecting them to the eligibility criteria:

- The research delineates the method step-by-step for identifying alternative applications.
- The method described in the research uses a technical innovation or product as input (or a technical knowledge base of a firm).
- The research should be written in the English language.
- The full text of the research should be accessible online.

The other articles delved, for example, into the concept of product platforms within firms, where a firm develops multiple products but are not explaining a method to find these diverse products. The content of the remaining articles centred on management strategies and other approaches. Additionally, there were articles explaining design strategies for conceiving innovative products. However, what consistently appears to be absent is the connection of a methodology to the discovery of alternative applications stemming from a technical innovation. This may be attributed to the prevalent use of generic terms within this search query. Employing the linking syntax W/n introduces constraints, resulting in a lesser amount of articles, yet it does not precisely narrow down the aim of this search.

The low number of valuable articles coupled with the absence of reference articles, i.e. the ones already identified in the exploratory search, prompts us to refine the search term towards more specificity. This entails incorporating terms associated in literature with the process of identifying alternative applications, a challenging task given the multitude of terms encountered in the exploratory search, including (1) technology opportunity identification, (2) business opportunity identification, (3) application exploration, (4) cross-industry application exploitation, (5) discovering uncommercialised research fronts, (6) extracting commercialization gap, (7) (as part of) technology forecasting, (8) (as part of) innovation forecasting, (9) technology development method, (10) new opportunity analysis, (11) technical innovation strategy, (12) Technology Opportunity Analysis (TOA) and (13) technology opportunity discovery (TOD). The latter term has been frequently used in recent years in quantitative studies investigating potential opportunities for a technological product. Additionally, it is essential to note that some terms serve as umbrella concepts, often encompassing the identification of alternative applications or opportunities for a technology as a step within the proposed method, while others are less prevalent in the literature, but are directly explaining the application-finding method.

After a process of trial and error, the following search term was devised:

```
TITLE-ABS-KEY((method OR model OR framework OR approach OR strategy OR process OR analysis) AND ((find* OR deriv* OR discover* OR develop* OR identify* OR explor* OR exploit*) W/3 ((alternative W/1 application*) OR (alternative W/1 product*) OR (potential W/1 application*) OR (potential W/1 product*) OR (promising W/1 alternative*) OR (different W/1 application*) OR (different W/1 product*) OR "alternative technolog*" OR "potential technolog*" OR “technolog* opportunit*” OR (business W/1 opportunit*))) AND ("existing technolog*" OR (existing W/1 product*) OR (existing W/1 mechanism*) OR (existing W/1 device*) OR (existing W/1 innovation*)))
```

The red highlighted words in the search term represent the modifications made. There is one alteration, besides all additions, namely the change from W/1 to W/3. We previously concluded that n=1 was a logical approach, but with the addition of new terms, a decision was made to adopt a higher value for n, thereby broadening the search scope a little more. However, this expansion was kept within limits to avoid completely disassociating the terms and compromising the W/n syntax. Ultimately, this modified search term yielded 111 results. The increase in the number of results cannot be solely attributed to the shift from W/1 to W/3, as, had this been the only change, the number of articles would have risen to 63. The observed almost twofold increase suggest that the added terms contributed enormously to the expanded outcome.

One might consider adding terms such as ‘identifying problems’ and ‘existing solutions’ to the search term, as the ultimate goal is to find issues related to a solution. However, this proved to be impractical, as it would result in 61.864 results.

This final search term yielded thus a total of 111 results, of which 29 were found to be relevant after title selection, 15 remained relevant after abstract selection, and, following a preliminary scan and identification of articles available online, 11 relevant articles were retained including the 3 articles found in the initial search. This indicates an addition of 8 new articles. Notably, these newly identified articles are predominantly sourced from the journals Technology Forecasting & Social Change and Scientometrics, with a focus on big data analysis (patents and scientific articles) to identify opportunities. It is crucial to note that the eligibility criteria were slightly adjusted. Articles were included if they incorporated a firm’s technological knowledge base as a starting point, rather than focusing solely on a specific technology. Without this adjustment, the result would have been a total of 2 relevant articles. According to the preliminary literature research, these 11 articles still do not encompass the entire narrative concerning application-finding methodologies. Only 1 similar article to the ones found in the preliminary search has been identified with this search. It can be inferred that a systematic literature review impedes us from obtaining the requisite information. The search term either introduced additional barriers, hindering comprehensive information retrieval, or conducts an unrestricted search, resulting in an information overload that complicates the extraction of valuable information details. This necessitates a shift towards a scoping literature review.

2.3. Scoping research

2.3.1. Objective

During the meticulous systematic literature review, the required articles, as noted in the previous section, were not all identified. Firstly, this can be attributed to the challenge of straightforwardly searching for ‘methods’ that ‘find problems’ to a ‘solution’. Despite the inclusion of this aspect in the search term, it yielded an excessive number of results. Even though these terms are indeed prevalent in the literature, the terms are not specific enough. Additionally, the search including ‘alternative applications’ did not yield the desired articles, despite these terms were also featuring prominently in the exploratory research. However, the combination with the other key terms proved too generic or too specific to identify most of the methods. The introduction of ‘technology or business opportunity’ led us into a research field that seems to be prevalent from 2013 onwards. This term was used to identify opportunities for firms possessing specific technological knowledge and exploiting this, or to become an ambidextrous firm. However, ‘opportunity’ does not solely relate to the discovery of applications for an existing technology but also extends to the identification of new innovations. Hence, the term ‘applications’ was scarcely mentioned in the abstracts or titles of these articles, or not in combination with the other key terms from the first search term. From this, we cautiously infer that there is a single research group from 2013 on using a consistent term, making their devised methods more easily discernible. Conversely, other scattered sources describe methods with slightly different terminology. The objective of this scoping literature review is to delineate this particular research group and, more importantly, to systematically identify scattered sources comprehensively, thereby shedding light on other methodologies within the field.

2.3.2. Scoping research explained

"The methods that researchers use to synthesise, organise, understand, and interpret existing literature vary widely depend on the discipline, the research questions being considered, the researcher's methodological orientation, the topic being examined, and the nature of existing research methods and findings in the knowledge domain" [19]. While a systematic literature review is often preferred by researchers as a method to systematically arrive at the existing knowledge base, this quote suggests that it may not always be applicable. In this study, the research field, in conjunction with the research question, constrains the feasibility of systematicity, necessitating a transition to a scoping literature review. The scoping literature review often entails a broad exploration of a specific topic to obtain a comprehensive overview without delving extensively into each facet. Nevertheless, the ultimate objective of this study is to delve deeply into the methodologies. Therefore a literature mapping approach will be adopted as a form of the exploratory scoping review [19]. Through the scoping method, we aim to identify multiple methodologies. Subsequent to the identification of various methodologies, a detailed examination of their characteristics will facilitate the discovery of comparisons and contrasts between them.

2.3.3. Scoping method

For the scoping literature review, the tool ResearchRabbit is used to explore similar work related to the 11 articles identified in the systematic literature review and those from the exploratory literature review. Additionally, references within each paper are examined. ResearchRabbit offers the option to search titles and abstracts for specific terms, facilitating the potential filtering of articles. Significant articles will be stored in a new folder within ResearchRabbit, which is subsequently scrutinised for similar work and its respective references. It should be noted that two articles are not present in ResearchRabbit [15, 16], likely due to their classification as conference papers. These papers are thoroughly examined, and any significant new terms identified are placed in Google Scholar and Scopus. Subsequently, articles that are found and are listed in ResearchRabbit are further examined following the previously described procedure.

2.3.4. Results

First, we attempted to establish connections between the 5 primary articles from the preliminary search, as described in Section 2.1.1, of which one article was not present in ResearchRabbit. These connections could not be identified by ResearchRabbit, thus there was no mutual referencing. Subsequently, similar work was examined in relation to these articles. It is noteworthy that the main topic of all these identified articles revolves around Open Innovation. However, an examination of abstracts using the search word ‘application’ yielded no relevant findings. This indicates that the research field towards problem-finding methods is scarce and inadequately delineated by conventional terminologies. Henceforth, our focus shifts towards the articles identified through the systematic literature review.

From 5 out of the 11 articles from the systematic literature review, a discernible research group emerged. In Figure 4, the 11 relevant articles identified from the systematic literature review have been depicted. Using ResearchRabbit, interconnections between these articles have been indicated, leading

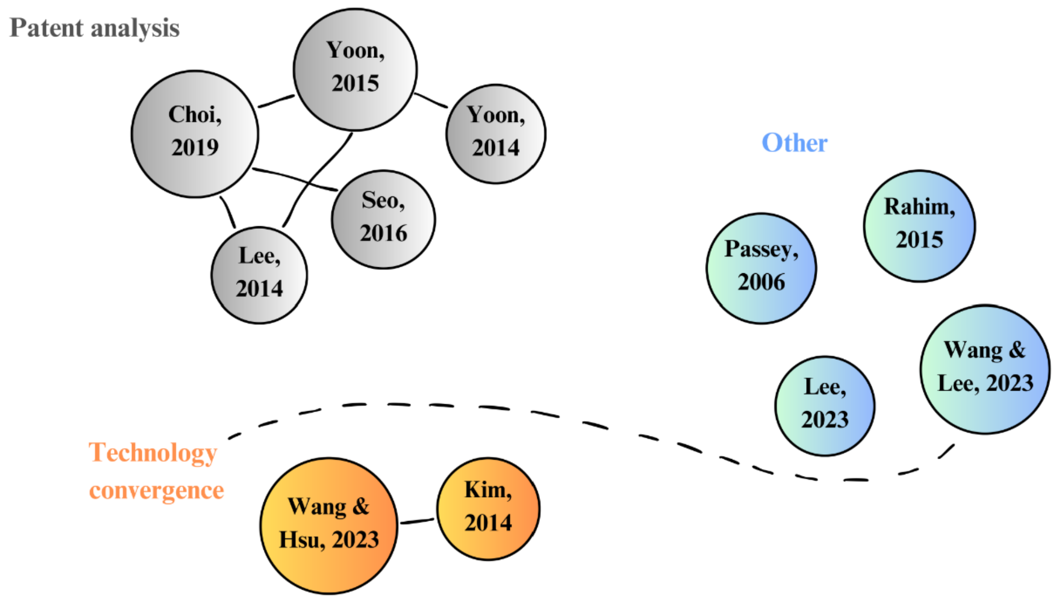


Figure 4: The division of found articles during the systematic literature review

to the formation of three groups: (1) Patent analysis [17, 20-23], (2) Technology convergence [24, 25], and (3) Other [1, 15, 26, 27]. The size of a circle indicates the degree of relevance as determined by ResearchRabbit, mostly based on the frequency with which the article is cited in other works. The first group predominantly comprises articles from the journal Technology Forecasting & Social Change, while the second group includes articles from Scientometrics. Subsequent research revealed that the article by Wang & Lee [27], also relates to Technology convergence. It is likely that a reference link is missing due to the simultaneous release of these articles, preventing mutual referencing.

By analysing the references and conducting a temporal analysis on the 5 articles from the first group, three relevant articles have been incorporated into this group: one older article by Porter from 1995 [28], who was the first to introduce the term "technology opportunity analysis", and two articles applying a patent analysis technique to specific cases [29, 30].

Through an examination of references and placing the articles from the second group and the article by Wang & Lee [27] in chronological order, it became evident that these three articles can be considered a subgroup within the first group. Technology convergence is, in essence, one of the techniques within patent analysis, but due to having its own term it has formed its own reference group. The three articles related to this topic were due to being a subgroup considered relevant, but no new articles has been added to this group as this topic is already being addressed with the key articles.

This leaves the analysis of Passey [26], Rahim [1], and Lee [15]. An analysis of Passey yielded two additional relevant articles to enhance the understanding of the technology roadmapping method and hereby the identification of alternative applications [5, 31]. Rahim's article resulted in one more relevant article [32].

Ultimately, the article by Lee [15] was scrutinised for references since it was not recognised in ResearchRabbit. During this examination, the term 'solution-mapping' was identified as a key term in the context of finding solutions to problems. Through snowballing and further exploratory research, four new articles were identified as relevant [3, 14, 33, 34].

2.4. Concluding remarks

We can conclude that a comprehensive overview of potential tools and methods has been identified to aid in the identification of applications for an existing technology. However, it is noteworthy that the majority of these methods are tailored to technology bases within a technological firm, and adjustments would be necessary for these methods when seeking applications for a specific technology such as the colour-changing and flexible material. Focusing the literature review specifically on methods tailored to a single technology proved challenging. Nevertheless, efforts were made to find articles that were as focused as possible on a singular technology, such as those demonstrating their methodology through application to a specific case. Figure 5 summarises the number of relevant articles found during each review type.

This figure illustrates that in the preliminary search of this literature review, we identified 5 relevant articles as reference points to validate the systematic literature search. These articles should be included among the resulting relevant articles from the systematic search. From the accurate search term, 3 relevant articles emerged, and an additional 8 emerged from the tailored search term. However, only 1 out of the total 11 articles from the systematic search corresponded to the reference articles. The conclusion drawn was that the literature landscape regarding problem-finding methods is not only scarce but also fragmented and disconnected across groups. The groups 'patent analysis', 'technology convergence', and 'other' were identified by ResearchRabbit. Subsequently, an analysis within this AI tool was conducted, exploring similar works. The 5 articles from the preliminary search yielded no new articles as the primary focus of the articles that showed similar work according to ResearchRabbit was on Open Innovation rather than on the exploration of alternative applications. Similarly, the 'technology convergence' group yielded no new articles as we discovered that this group is actually a subgroup of the 'patent analysis' group, and we concluded these were on their own the relevant articles from this particular subgroup. From the 'patent analysis' group, an additional 3 articles emerged. Within the 'other' group no cross-referencing was present as these were the remaining articles that did not belong to a topic, resulting in each article leading to new ones, often addressing novel techniques. Ultimately, it was chosen to proceed with the resulting 25 relevant articles for further analysis.

The approach outlined in Figure 5 contributes not only to this study but also to other literature reviews dealing with similarly thorny issues. By a "thorny problem", we refer to the challenge of conducting a

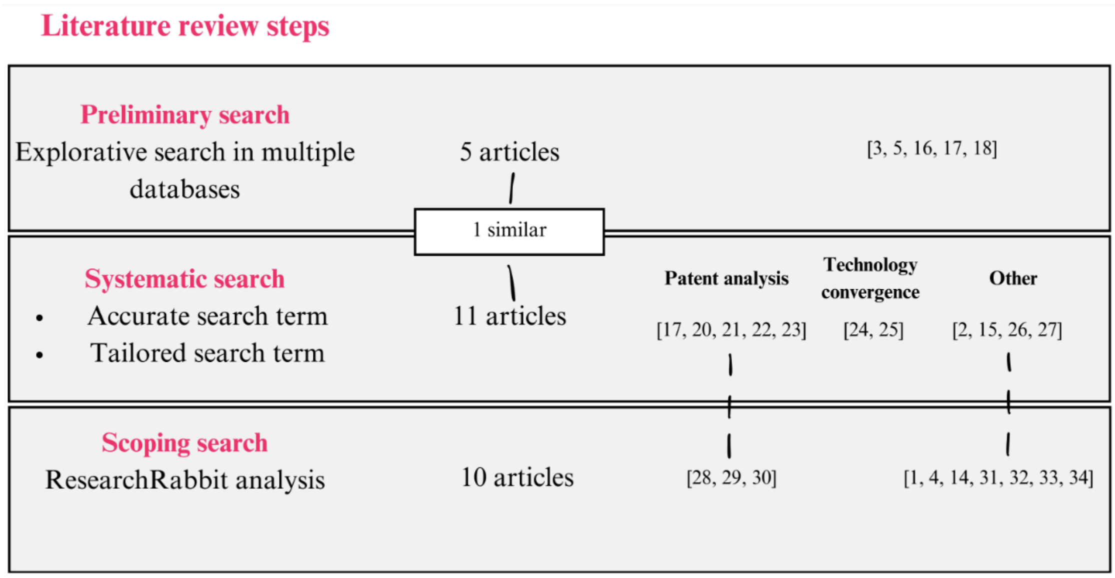


Figure 5: Overview of the proposed literature review

literature research on a topic that is both scarce and unconnected across various dispersed groups that uses diverse terminologies. The difficulty increases when one research group overshadows individual articles by extensively using generic terms, which become hidden by the great volume of literature, rendering filtering impractical. In such situations, one could execute a similar literature research process, wherein an initial brief exploration of the literature is conducted to identify key terms. Subsequently, during the systematic search, an accurate search term is employed, which can then be refined to incorporate key terms used within specific groups to identify more relevant articles. Eventually using the AI tool ResearchRabbit enables the identification of new groups despite the previous tailored search term. This literature process has proven fruitful in the present study and holds promise for future research.

Although ResearchRabbit has categorised the groups as described in Figure 5, we observe a different grouping of articles when also taking into account both the articles from the preliminary search and those derived from the scoping search. This classification is as follows: (1) TRIZ, (2) Cognitive, (3) Roadmapping, (4) Patent analysis. These groups are selected based on the primary component addressed in these articles. This categorisation is made to systematically extract problem-finding techniques from similar articles, subsequently positioning these techniques within a problem-finding overarching process. It is important to note that each group is not isolated from other groups as certain TRIZ techniques may also be present within other articles and vice versa. Moreover, the first three groups primarily encompass qualitative techniques, whereas the last group encompasses all quantitative techniques, which are all based on patent analysis. Here, the qualitative groups represent the scattered articles in the 'other' group defined by ResearchRabbit, while the patent analysis is presented as already a group, 'patent analysis' and 'technology convergence' combined, within the literature. This quantitative group concerns the objective analysis of patents and scientific articles through a program aimed at uncovering opportunities for a technology. These quantitative methods could be collectively identified under a single term, which makes it easy accessible during a systematic literature review. There may be different execution techniques, but for now, we categorise them under one group called 'patent analysis' as is done in the literature. Chapter 3 will delve deeper into various identified methods, strategies and techniques, but an overview of the categorisation of the different identified groups can be seen in Figure 6.

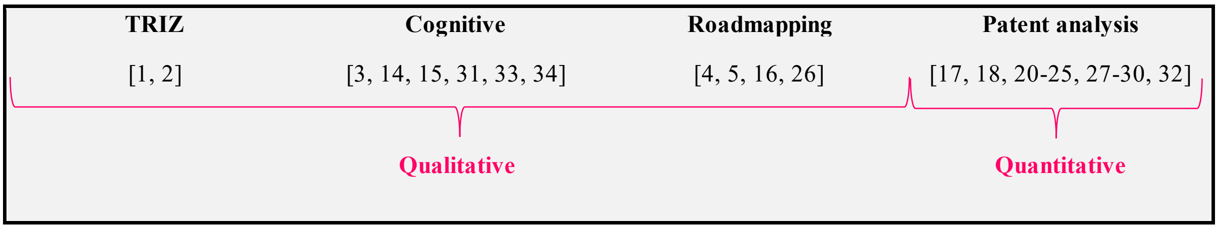


Figure 6: The categorisation of the relevant articles

3
Literature review: synthesis

The articles obtained from the literature review was found to be categorised into four groups: (1) TRIZ, (2) Cognitive, (3) Roadmapping, and (4) Patent analysis. Each of these groups adheres to a principal component to which the groups are named after. In organising these groups in this manner, our aim is to encounter various methods for identifying alternative applications for a technology. This chapter first delves into the groups at an individual level and the shared commonalities in the proposed methods of the according relevant articles. Here, answers are provided to SQ1: “Which methods within the literature contribute to the research field of identifying alternative applications based on a technical innovation?”. Subsequently, a concluding section will provide clarity on the overarching generic steps of a problem-finding process and how these steps are derived from the various four groups.

3.1. TRIZ

Based on the findings of the literature review, the study by Bianchi et al. [2] stands out as the first to use TRIZ as groundwork for developing a method to identify alternative technological applications based on a firm’s technologies, specifically focusing on small- and medium-sized enterprises (SMEs). In doing so, they show a reversed perspective, considering that TRIZ typically constitutes the theory of problem-solving rather than the theory of problem-finding. They state that SMEs often lack the resources to be able to create innovative products and processes. However, they also note that SMEs, in contrast, exhibit flexibility and adaptability compared to large firms, enabling them to quickly adjust to circumstances. Hence, the suggestion is made for SMEs to commercially exploit their own technology through the practice of Open Innovation.

The identification of alternative applications is however a challenging aspect of exploiting their technology due to the cognitive limitations of SMEs and the absence of multidisciplinary competence. To address this, Bianchi et al. [2] propose a structured approach to identify these applications, incorporating the philosophy that “somebody, someplace, has already solved your problem, or one very similar to it”. This notion suggests that, at an abstract level, similar technical problems occur across various technological domains, and solutions already exist in some of these domains, which can thus be applicable to a similar problem. When one identifies where a problem is located, which can be addressed with their devised technology, there is potential for profit. By employing TRIZ techniques, Bianchi et al. [2] aims to overcome psychological inertia, encouraging SMEs to think beyond their own experiences and knowledge and find these problems.

Within TRIZ, a generic approach is presented for problem-solving, which entails initially analysing the specific technical problem, then abstracting the problem and disassociating the problem from its context. Subsequently, abstract solutions can be identified, from which specific context-based solutions can be derived. This is illustrated in Figure 7a Bianchi et al. [2] propose a reverse approach, visible in Figure 7b. The detailed steps are explained in Table 1.

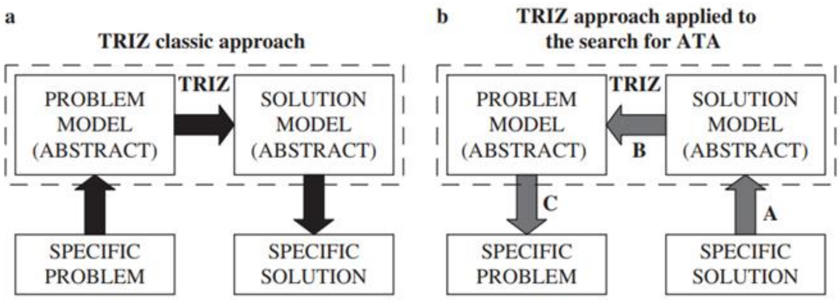


Figure 7: : (a) The conventional TRIZ problem-solving steps, (b) The inverse TRIZ approach proposed by Bianchi et al. [2]

Table 2: Inverse TRIZ method proposed by Bianchi et al. [2]

1.	**Definition of the technology**	In this step, the characteristics of the technical solution are found, which were known as requirements for the original problem. To achieve this, the technology description framework is used, which involves answering a multitude of questions about the technology organised across the dimensions of function, structure and size.
2.	**TRIZ-based analysis of the technology**	As depicted in Figure 7b, the second step involves abstracting the technical solution. This is achieved by dissociating the solution from its specific context. To accomplish this, two TRIZ-based tools are employed: (1) Functional Analysis (FA) to identify universal functions that align with the technology, and (2) Evolution Potential Analysis (EPA) to analyse the current state of the technology.
3.	**Selection of abstract problems**	From step 2, potential problems that can be solved emerge. An initial list of the abstract problems is established.
4.	**Identification of the ATA**	In this step, one returns to the specific function of the technology, reducing abstract problems to specific applications. This involves employing a catchword-based search across various repositories. A list of Alternative Technical Applications (ATA) is established.
5.	**Strategic positioning of the ATA**	This step is not depicted in Figure 7b, but adds a decision-making component to the method. The list of potential applications is subjected to the criteria of technical feasibility, market attractiveness, and innovativeness to determine which ATA the SME should focus on. A scoring method is used.

While Bianchi et al. [2] focused on assisting SMEs with this inverse TRIZ method, Rahim et al. [1] propose this reversed TRIZ for application within chemical engineering. Chemical products can hold enormous value in other technical fields. When problems of a chemical nature arise, costs can be shared and therefore gained by sharing solutions between fields. This is highly advantageous given the high cost of research within the chemical industry. Cost reduction and innovation are very desirable. However, there is a lack of systematic and effective cross-disciplinary methods for chemical engineers in the literature. Hence, Rahim et al. [1] have also delved into the inverse TRIZ method. However, an adapted version as this method is to apply to chemical engineering problems. Whereas the traditional inverse TRIZ progresses from specific solution to generic solution, then to generic problem, and finally to specific problem, the inverse TRIZ tailored for chemical engineering encompasses the steps as visualised in Figure 8.

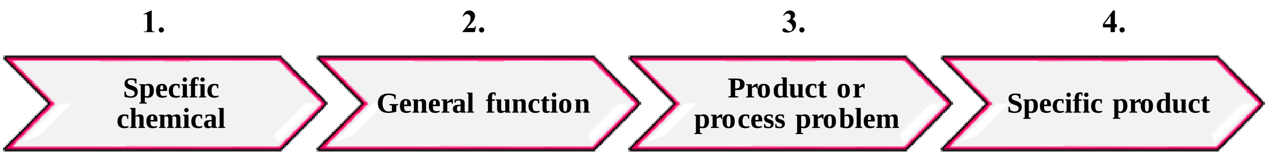


Figure 8: Inverse TRIZ for chemical engineering proposed by Rahim et al. [1]

To achieve these steps, it followed the TRIZ tool Inverse Function Oriented Search (IFOS), which is also proposed by Souchkov [16], for new product development. This inverse TRIZ tool makes use of a component analysis to establish the new technology, of a function analysis to integrate the targeted function, and a function-morphological analysis to eventually find different industries the function is applicable to. A Main Parameter Value (MPV) is set up to find the level of compliance between the generic solution and the new technology, and define the key problem the new technology can solve.

3.2. Cognitive

Where TRIZ tools offer means to eliminate cognitive limitations, several researchers have focused on expanding the mind and knowledge through the offering of other cognitive strategies, aiming to achieve a similar goal: the discovery of alternative applications for technical innovation. Danneels and Frattini [33] term this objective as technology leveraging and propose their steps as the 'de-linking' of technical innovation from its current application context to uncover other applications, followed by the 're-linking' of the technology to a new application. Their steps and proposed sub-steps are visualised in Table 3.

Table 3: The de-linking and re-linking method proposed by Danneels and Frattini [33]

1.	**Characterising the technology**	In this step the function of the technology should be understood, especially its core functionality.
2.	**Identifying potential applications**	For this step, desk research is proposed to identify technologies with similar core functionality and study how they have been applied. Furthermore, it is advised to interact with experts, trade shows, focus groups, and problem solvers.
3.	**Choosing from the identified applications**	To be able to make a choice simulation studies could help or subjecting the found applications to three criteria: technical feasibility, market attractiveness and innovativeness.
4.	**Selecting an entry mode**	To entry the market with the new application, multiple options are possible among other collaborating with a third party and licensing the core technology.

Danneels and Frattini's [33] exploration of technology leveraging argues that desk research can assist in identifying alternative applications, as well as the interaction and brainstorming with experts or focus groups. In addition, the mechanical engineering researcher Jin Woo Lee and his research team delve into more detailed cognitive strategies that can be employed during brainstorming sessions with engineers [3, 14, 15]. They observe that within engineering design processes, the focus often lies on solving a problem, leading to the frequent execution of problem-first design practices. The steps required for this approach are well-known among engineers, but reverse thinking and the tools for solution-first processes have been underexplored. These design processes start with a technical solution, subsequently diverging into various problem applications, before converging to a single problem application. They term this process solution mapping, a concept which Danneels and Frattini [33] referred to as technology leveraging.

From literature we concluded that many terms were used for the so-called solution-first processes. Lee et al. [3, 14, 15] also noticed this. They mentioned that some refer to them as technology-driven processes or opportunity recognition processes, but here the focus is on extracting more value from a firm's technological patent by exploiting it for which there are multiple ways. Interestingly, they also observed that research in bio-inspired design processes do not exploit a firm's technological patent but rather draw inspiration from biological solutions found in nature and exploit this mechanism. Many problems encountered in society have already been solved somewhere in nature. For instance, the adhesive capacity of the gecko feet has been thoroughly examined, leading to the development of a biomimetic material applicable in construction and inspection [34].

Lee et al. [3, 14, 15] delineate a step-by-step plan for solution mapping along with the corresponding cognitive strategies and tools required for each step, referred to as the Solution Mapping Design Tool. This plan originates from conducted think-aloud studies, wherein they analysed engineering practitioners' during solution mapping and obtained their cognitive patterns. The found solution mapping behaviours were: "substitute way of achieving function", "change geometry", "identify and relate to specific industry", "change product lifetime", "cover or wrap", "attach product to user" and "add to existing product". They stated that divergent thinking is a needed component to be creative. Consequently, the aim of their presented tool is to foster divergent thinking among engineers. The Solution Mapping Design Tool supports design processes through two provided components: an analysis scaffold aiding engineers breaking down a technology into functionalities, and an extensive list of various industries to prompt consideration on application areas. Their proposed stages of the solution mapping process are visualised in Table 4.

Table 4: Solution mapping strategies placed in solution-first method by Lee et al. [3, 14, 15]

1.	**Develop a solution**	Create a technical solution. For example, a mimicked mechanism from nature.
2.	**Explore characteristics of the solution**	Possible approaches for this step: "describe enabling functions of the solution", "reframe the solution using alternative perspectives", "compare the solution to existing possible competitors", "emphasise different or multiple descriptions of the solution characteristics".
3.	**Explore potential industry sectors**	Possible approaches for this step: "align the solution to needs in broad industry sectors to identify industry matches", "vary framing of the solution based on stakeholders' interests".
4.	**Select industry sector for application**	Possible approach for this step: "prioritise an industry sector from among identified applications".
5.	**Specify a problem application**	Specify the problem application in detail, and set up a plan.

3.3. Roadmapping

The concept of roadmapping has been present within the business environment for a while. In 1997 Groenveld [5] discussed the product-technology roadmap, developed at Philips Electronics to improve the awareness of serving markets with appropriate products at the right time and to encourage cross-functional processes within the firm in both the short and long term. Implementing a roadmap within a firm facilitates a better integration of business and technology strategies, thus instigating new product ideas and initiating the product creation process. When visualising business processes, various possibilities become apparent. Groenveld [5] advocates for a standardised format for roadmaps, while acknowledging the necessity to accommodate the openness within the firm. The steps towards a roadmap are visualised in Table 5.

Passey et al. [26] also suggest that to foster innovation within a firm, the boundaries of a roadmap must be pushed, facilitated by concept visioning and scenario building. Concept visioning means that user demands become an internal driver of the firm. Furthermore, they introduced the term “innovation roadmap event horizon”, describing the point on a roadmap where product concept innovation starts. They propose setting up a scenario funnel (i.e. scenario building) to reach and analyse potential future horizons by conducting a Scenario Field Analysis (SFA). Ultimately, their proposed method for developing a roadmap comes down to the steps visualised in Fig. 14.

Although Sheu & Lee [4] do not immediately use the term roadmapping, they propose a business process for opportunity identification in the form of a Systematic Innovation Process (SIP). They outline three types of innovative problem-solving approaches: a flash of genius, an empirical path involving brainstorming and trial-and-error approaches, and a methodical path employing a systematic approach. The first two approaches heavily rely on luck, which is why Sheu & Lee [4] advocate for a structured method for finding a solution. While their method primarily involves attempting to find a solution, their innovation process goes further and adds a step: application exploration. This is to ultimately achieve cross-industry application exploitation. For the Application Exploration stage, they propose the following non-TRIZ tools: Voice of Customer (VOC) or Quality Function Deployment (QFD), Product Platform Analysis (PPA), or a product-technology roadmap. The latter refers to what this section is about. The first tool aids in finding applications that suit the consumer, while the second tool examines whether derivatives of the product can exist.

Table 5: Roadmapping process by Groenveld [5]

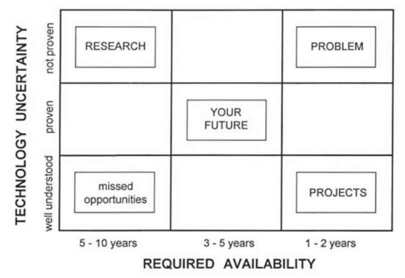
1.	**Perform a QFD in the start-up phase**	Product managers and design teams conduct QFD to visualise customer requirements. This process delineates the requirements, i.e. the characteristics of a new product. QFD frequently serves as the starting point for roadmapping within firms, as it can lead to innovative opportunities.
2.	**Get a common vision in the roadmap planning phase**	The outcome of QFD established a common vision for products and technologies in the future. In this planning phase, a forward-looking perspective spans a period of 4-6 years to anticipate the development of technology and products over time or how a particular technology will influence a product function.
3.	**Create an innovation matrix**	The innovation matrix illustrates the relationship between the required availability of a technology and the uncertainty. These terms relate to technologies that need to be implemented in a potential new innovation for the firm. Technology uncertainty concerns the extent to which the technology has proven to be working. Required availability means how effectively and quickly a firm could implement the technology into an innovation. This can be mitigated by allocating more resources to a particular technology, but this also requires time. The innovation matrix is depicted below. In the case of a missed opportunity, it implies that the technology is already available and working, but the firm would take 5-10 years to have it implemented into an innovation, indicating a misallocation of funds. In the case of a problem, it concerns the urgency of bringing an innovation to market, but obtaining the technology within that timeframe is not guaranteed. The optimal balance in the innovation matrix is achieved within the box "your future". Such an innovation matrix could also be created for a product. 
4.	**Map the technology matrix onto the product matrix**	Once an innovation matrix has been developed for a product and for the technology in step 3, both matrices are superimposed and analysed to identify potential gaps between the availability of products and technologies.
5.	**Conduct a portfolio analysis for the products/technologies**	In this step, the availability of the product/technology within the firm's portfolio is examined.
6.	**Draw up the resulting processes for a new product/technology**	Ultimately, a decision is made to invest in a particular technology or product, and processes are set in motion.

Table 6: Roadmapping process by Passey et al. [26]

1.	**Identification**	Market research is executed to analyse consumer behaviour and address the availability of the new technology. Deduced from this information a vision for new products is identified, called concept visioning.
2.	**Analysis**	A scenario funnel is set up, where upon a Scenario Field Analysis (SFA) is executed, meaning a description of each scenario is assessed through internal and external focus groups to validate the possibility and added value of each scenario.
3.	**Design criteria**	Design criteria are set up.
4.	**Exploration**	It is examined which scenario, i.e. which future horizon, will become the objective.
5.	**Selection**	A scenario is selected and a plan to achieve this future scenario is created.

3.4. Patent analysis

Whereas the preceding sections primarily focused on qualitative methods, this section will delve into quantitative methods, i.e. the different patent analyses we encountered. With the emergence of big data and consequently the proliferation of numerous technical patents and scientific papers in databases, the approach within firms has evolved towards searching for applications for their technical patents and exploiting them. This is a quantitative process of technology forecasting, and is called within this field technology opportunity discovery (TOD), where technology opportunity is defined as “a set of possibilities and potentials for technological advances in general or within a particular field” [17, 21, 23].

The emergence of research in TOD methods holds significant value for the technology manager, strategic planner, or market analyst [21, 23]. TOD research focuses not only on identifying promising technological applications to seize business opportunities but also improves technical competitiveness by reducing trial and error within R&D and minimising investment risks. This occurs as TOD methods increasingly focus on the specific technical knowledge base of a firm and conduct analyses to filter out the best customised opportunities. The TOD research stream aims to obtain technology intelligence. Technology intelligence concerns the degree to which technology is understood, how it will evolve and how it can be used for profit. To acquire crucial information on the potential of a technology, a firm must possess extensive knowledge about the technology and therefore quite an amount of technology intelligence to process this knowledge. When technical documents, knowledge and experience are insufficient, uncertainty arises regarding the potential actions a firm can or should take with a technology. Currently, the abundance of technical documents is adequate to lessen the uncertainty, but the technology intelligence of experienced experts alone is not sufficient to minimise the uncertainty as much as possible and large-data computer analyses will have to be employed. With computational power, a much higher level of technology intelligence could be achieved. Relying solely on an expert’s experience to obtain this intelligence is not realistic, because of the extensive information load, i.e. technical documents, that is currently available [20]. However, several studies suggest combining expert-based methods with larger-scale database methods [17, 18, 20, 21, 23, 24, 30, 32]. Together with the expert's knowledge and visualising future trends of technologies, it becomes possible to anticipate technology opportunities [20]. A human touch is namely still effective in checking for example the clusters of patents an algorithm has established. There are two types of TOD: anticipating new technology or applying existing technology [17, 23]. This study focuses on the latter, similar to SMEs. As prior stated, SMEs have fewer resources and therefore aim to exploit their technology.

Compared to the qualitative processes, quantitative processes follow a similar purpose, only the amount of data is greater, the recognition of a technical solution in other fields is determined by algorithms, and data collection is necessary to include in the process. Ultimately, a logical conclusion still needs to be drawn for the most promising technology opportunity by the experts and decision-makers equivalent to the steps in qualitative processes. In Appendix A, all processes from the key articles explaining a quantitative database method are presented in steps quoted from their corresponding articles. Each article divides these steps differently based on their proposed method, but the overarching trend found within the quantitative database methods is visualised in Figure 9.

To identify alternative applications within a quantitative process involving patent analysis, the initial step is to collect the data, i.e. the patent set. To process the data, the patents need to be transmitted into specific formats. This process is referred to as data preprocessing. Subsequently, the patents with the correct format can be used as input in the algorithm, i.e. the data processing stage, which will identify certain links or differences between patents or patent clusters. From the information obtained in this process, technical opportunities can be identified. From these technical opportunities, i.e. potential alternative applications for a particular technology, the most promising one must be selected.

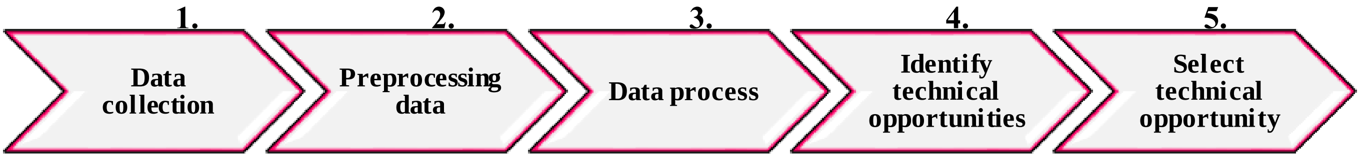


Figure 9: Found overarching trend of quantitative method steps

Where steps 4 and 5 are similar in each process, with only the substantive outcome varying but not the conceptual task in these processes, steps 1 through 3 can vary significantly in approach, as illustrated in Table 7. In step 1, data collection may be based on either a core patent of the firm or an existing technology [17, 21, 23]. In this process, a patent family is identified using search terms and sometimes through text mining [22]. It may also occur that a comprehensive technical database serves as the basis for data collection [20]. Steps 2 and 3, respectively the preprocessing of the data and the actual data processing, are closely linked. The proposed process data method suggests a preprocessing approach that aligns with this, yet there are still several possibilities. With preprocessing the data, research mainly focuses on organising patents and scientific articles into clusters or in chronological order [20, 22, 24, 25, 30], or on identifying key word and key functions [17, 18, 21, 23, 29, 32]. Based on these processes, the data is further processed in multiple ways in step 3.

Table 7: Different approaches for step 1-3 in a quantitative problem-finding method

STEP		APPROACHES
1.	Data collection	• Based on core patent and find patent family [21] • Based on existing technology and collect patents [17, 23] • Select appropriate database and find basic patents and find patent family [32] [30] • Extract product information from patent database using text mining [22] • A very large database (e.g. Korean patents registered since 2000 in an entire technology field) [20] • Constructing a technological knowledge flow network based on patent data [25]
2.	Preprocessing data	• Find key patent using Scree test and perform a two-step patent citation [32] • Constructing the patent-keyword frequency matrix and create a keyword vector [29] • Create a patent citation network and cluster patents into *k* technology groups [24] • Create expert-based technological attribute-application table to identify basic opportunities by multiple keyword matching [21] • Apply morphology analysis and define functions and attributes by experts and using text mining [23] • Extraction of product function using Subject-Action-Object (SAO) structures [17] [18] • Generating product connection rules employing association rule mining [22] • Focus technology fields are selected for each year and technological sequences are generated [20] • Papers and patents are divided by year, noise data is removed, and they are converted into text format compatible for text mining. Then clustered in topics using the Lingo Algorithm [30] • Core-periphery analysis is used to identify peripheral technology classes [25]
3.	Data process	• Technology performance analysis applying 39 TRIZ parameters and implementation of technology performance map [32] • Conducting novelty detection technique [29] • Select *m* core patents that may provide technological convergence and extract representative keywords [24] • Iterative action-object structure text mining of patent family [21] • Generating linking grid by calculating association [23] • Semantic functional similarity measurement [17] • Explore the novelty of potential products and measure the potential value of product opportunities [22] • Frequent sequential patterns are explored using precedent enterprises' sequence database using PreFixSpan algorithm [20] • A hierarchical structure of the technology is generated [30] • Association rule mining (ARM) to discover technology convergence with emerging technology classes [25] • Analyse the differences between the topics of scientific papers and patents, and use outlier detection method to identify outlier points [18]

3.5. Concluding remarks

In this chapter, four distinct groups have been discussed, derived from the larger set of 25 relevant articles from the literature review. This divergence from 1 group to 4 was needed to uncover potential different problem-finding processes. Each group brought forth key information for the problem-finding method, with one group contributing more than the others. For instance, the proposed reversed TRIZ, the presented cognitive processes and quantitative patent analysis provided very clear steps for a problem-finding method with in addition various approaches to execute the steps. In the cognitive subsection, more approaches emerged to identify certain alternative applications. Additionally, interesting approaches arose from the section on roadmapping, however these are not applicable to the presented case study of this research, but rather within a firm.

In examining all the outlined processes and approaches in this synthesis of the literature, we find a common thread in identifying problem applications. The research has made us realise that technical innovation must first be defined or characterised by identifying the main function and sub-functions. These functions are then generalised and can be recognised in other application fields. A choice from these applications is made based on various criteria depending on the technology or the firm. These steps are depicted in Figure 10.

While the established four steps are clearly retrieved from the presented processes of Bianchi et al. [2], Rahim [1], Lee et al. [3, 14, 15], and Danneels and Frattini [33], it may be more challenging to link the presented quantitative steps of Figure 9. It has been noted that in patent analyses, a patent set is first collected. This set is based on the characteristics and function of the technology, aligning the presented approaches for this step with step 1. The preprocessing of the data is seen as an extra step that needs to be taken in the quantitative method, but is for the generalisability of this process included in step 1 as also the preprocessing occurs based on characteristics of the technology patent clusters. Within the data process, the description of the technology or the function is often generalised and semantics are determined to find equivalent patents placed within a different technical field. This step within a quantitative process can thus be aligned with step 2 of the generalised process in Figure 10. Subsequently, the last two steps are similar as alternative applications still need to be identified and a promising one must be chosen whether it is a qualitative or a quantitative process.

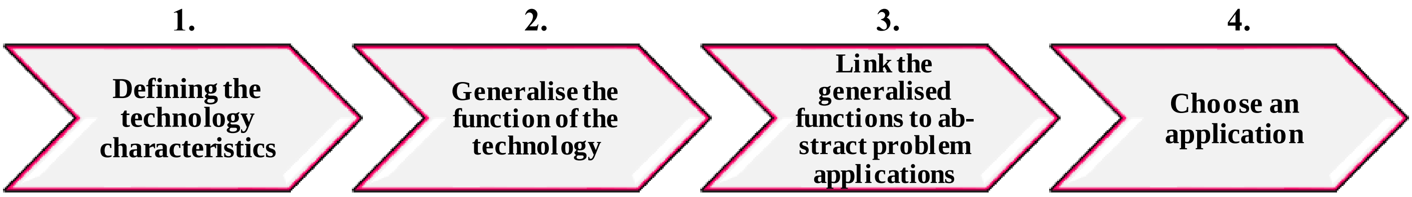


Figure 10: Common thread found in problem-finding methods

We can conclude that the four presented steps are the main steps of a problem-finding process. However, it is evident from this chapter, which is presenting information from multiple groups, that there are various approaches extracted from each group to execute these steps. These approaches will be analysed per step in the following chapter.

4

Process analysis

This research has thus far established two things. Firstly, it has been observed that the research field concerning systematic methods for deriving multiple problems from a single solution is rather sparsely populated and unconnected in dispersed in separate groups. The existing methods are difficult to unravel, and most of them do not seem applicable to a standalone, innovative technology. In other words, there is a lack of a handbook or guidelines similar to those available for solution-finding methods. It is not simply a matter of reversing these solution-finding methods. Such a perspective is too short-sighted. Through the literature review, we have illuminated the sparsely populated research field and gained insights from existing techniques and methods. While some researchers have already outlined specific step-by-step processes, others may not consciously follow these steps, yet their actions do fit within such a process. This brings us to the second established observation. The process of identifying problem applications consists of four crucial main steps: 1) *Define the technology characteristics*, 2) *Generalise the function of the technology*, 3) *Link the generalised functions to abstract problem application (fields)*, 4) *Choose an application*. We have been able to identify various approaches for each step from the literature, which we will further explore in this chapter.

By executing the identified steps and the associated approaches, along with the information regarding the case study as described in Section 1.1, we can analyse the process and the interconnection between steps and the various approaches. These observation will serve as an answer to SQ2: "How do the problem-finding methods found in the literature compare to each other?". Note that not every approach is implemented due to the inherent characteristics of each approach. The case study focuses on an individual technology, making quantitative methods often inappropriate or overly cumbersome. Nonetheless, these methods are still mentioned, explained, and included in the final overview. Each section of this chapter corresponds to one step in the process.

Given that we will delineate and execute various approaches in each section, which represents a step within the problem-finding process, this chapter is cumbersome. Hence, a vertical line from this textbox on the right has been placed in this chapter to guide the reader through crucial points in this chapter. This line also facilitates quick scanning through this chapter. The final station of this line is the last section of this chapter, where a summary of each section, and thus of each step and the drawn conclusions, can be found.

4.1. Define

STEP 1

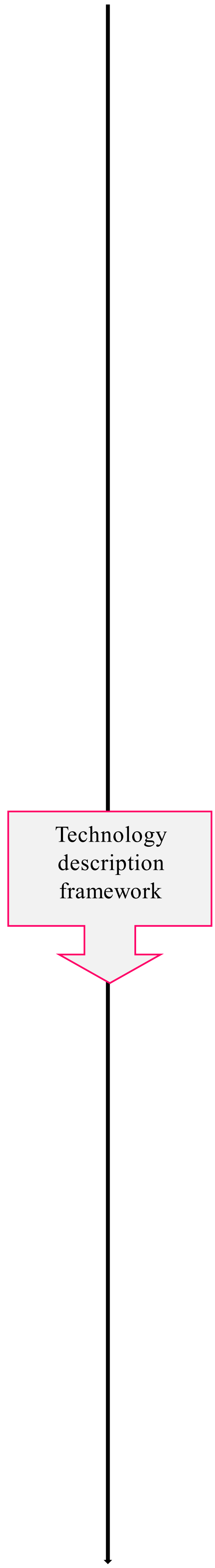
For the process of identifying problems for a technical solution, *defining the technology characteristics* has been established as step 1. Within the literature, various approaches towards this step are delineated, which are:

- **Technology Description Framework (TDF).** Based on the dimensions of function, structure, size, material and performance, questions are answered [2].
- **Basic keyword set.** Based on the categories of usage, technology, and product, keywords and their synonyms of the technology are categorised [21].
- **SAO analysis (1/2).** Based on the subject-action-object relationship, wherein the technology serves as the subject and therefore forms the solution, a clear and short functional description is delineated [17, 18, 21].
- **Morphology analysis (1/2).** Based on the physical and functional conceptual dimensions (e.g. module, function, process, and physical structure) various possibilities, referred to as shapes, are identified that express the appearance and functionality of the technology in short [23].
- **Quality Function Deployment (QFD).** Based on a customer survey, functional requirements and thereby characteristics are identified for an improved technology [5, 32].

In this section, the approaches are discussed, implemented when feasible and valuable and their results are assessed.

4.1.1. Implementation approaches

The approaches scaled under the first step within this research all offer distinct perspectives on the characteristics of a particular technology. By dissecting these approaches and juxtaposing their objectives and outcomes, we can discuss their relevance to this study.



The **Technology Description Framework (TDF)** is used to describe and understand the technology in a structured manner. By assessing several dimensions of the technology, each capturing different facets of the technology, it becomes feasible to gradually get a grip on the technical innovation. Bianchi et al. [2] used the following dimensions: function, structure, size, material and performance. By answering questions about these dimensions the assessor acquires insights into the capabilities and limitations of the technology. We used the proposed dimensions for our technology, see Table 8.

Table 8: Description framework

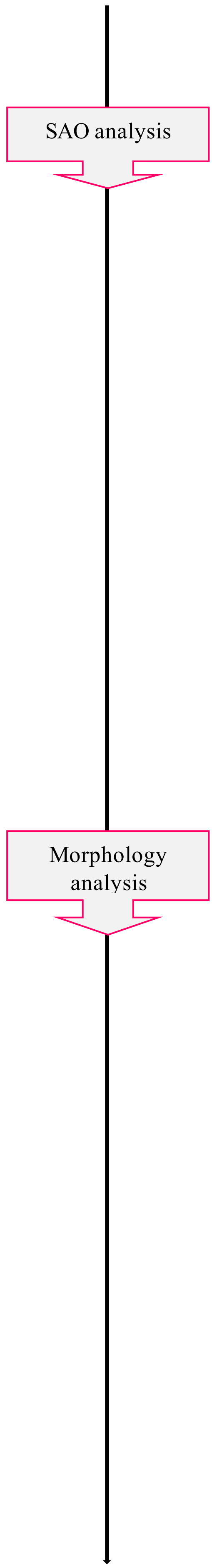
Dimension	Characteristics
(a) Function 'what does the technology do?'	The technology is a colour-changing material that, when pressing with an x amount of force, changes colour. The threshold value x can be adapted due to making incremental changes in the design. The technology serves as a sensor to estimate an applied pressure by giving visual feedback in terms of colour change. The material is flexible, which means the sensing function could be applied onto non-flat surfaces.
(b) Structure 'how is it configured?'	The key element of the technology is a soft blue bumpy sheet with square bumps on it. This layer is interlocked between two other layers, of which the bottom layer is a red colour and the top layer is transparent and flexible. This construction allows for colour change when pressure is applied to the top layer as the flexible layer causes the soft bumps to spread out and thereby show less blue pigment vertically and thus appear transparent. These square bulges can also take on other shapes and sizes. The flexible plastic top layer can take on different rigidity and plasticity and the soft material can take on different softness. The colour change can also take on different colours, but not every possibility. The coupling of the layers is done using a very thin layer of transparent silicone used as

		glue. The technology can have different configurations (change in stiffness, softness, or having an extra layer) and colours.
(c)	Size 'how big is it?'	Bulge height (h): min. 0.4mm Bulge size (s): min. 1x1mm^2 Groove width (w): min 1.4mm Sheet thickness (t): min. 4.975mm Sheet area (A): unlimited Max number of layers: 4
(d)	Material 'what is it made of?'	Top layer is generally made from PP0.075 Bulged blue middle layer is generally made from Ecoflex 00-20 with blue pigment Optional plastic middle layer is generally made from LDPE0.05 Flat red bottom layer is generally made from Ecoflex 00-20 with red pigment All materials need are skin safe.
(e)	Performance 'how well does it do it?'	Efficacy Enhanced estimation of pressure during MLD. Increase in patient's confidence and autonomy. Lower weight: whereas for the sheet the weight is in tens of grams, the current robotic sleeves capable of performing the MLD at home weigh several kilograms. This weight reduction makes the sheet portable. Smaller size: compared to current robotic sleeves that can perform the MLD at home this sheet decreased in size enormously, is rollable and is portable. Efficiency Reduction in costs Reduction in materials Limitations Constraints in materials used. No market research has been done.

Lee et al. [21] examine attributes of a technology such as shape or material, which determine the type of application the technology fulfils, or in other words, the opportunity it presents. Whereas Bianchi et al. [2] referred to dimensions, we discuss attributes here. Although the words carry the same meaning, the approach shifts and it is not a matter of answering some questions. Acquiring the attributes is part of the proposed process of Lee et al. [21], called the two-stage patent analysis. They have combined expert-based methods with larger-scale database methods. In their process a distinction is made in finding common versus uncommon opportunities. To identify common opportunities, an expert-based technological attribute-application table is constructed, followed by the identification of applications through multiple keyword matching. Uncommon opportunities are discerned through an iterative action-object (AO) analysis. It is observed that characterising the technology resides in the creation of a basic keyword table and the formulation of the initial AO set of the technology within this process. Both steps will be executed, each forming an approach in itself.

Basic keyword set

The **basic keyword set** comprises of keywords for the three categories usage, technology and product. The keywords are normally derived from the initial patent set consisting of the firm's patents, technical documents, journal papers, and other publications. Some filtering techniques are used and ultimately the final keyword set is chosen based on term frequency. We will not delve further into this term, but it essentially indicates which keywords are truly relevant. The final table that is formed with the keywords per category showcases the technology and capabilities of the firm. Our basic keyword set is found in Table 9. Because we drew upon the insights gained from the preceding master thesis, which delineated the design of the technology of this



case study, and the execution of various search queries, the basic keyword set was formulated without the use of an initial patent set and term frequency.

In the process of formulating the basic keyword set, which ultimately facilitates the discovery of new patents and therewith creates a pool of ideas, Lee et al. [21] define the found ideas as common opportunities. Uncommon opportunities could be found using **Subject-Action-Object (SAO) analysis** according to Lee et al. [21] . It can show relations between subjects, actions and objects in a given text, but also identify logical relationships, such as functional relationships. An SAO structure can be viewed as a problem-solving framework, in which AO identifies the problem, and the subject provides the solution. For instance, in the example "soap cleans dirty hands", soap (S) serves as the solution to clean the dirty hands (AO). The idea behind this approach is that the same AO may appear in patents, but different solutions may be proposed. Alternatively, in our case, instances could be examined where the same solution is used to address a different problem. In their method, Lee et al. [21] initially establish an initial AO set with an expert, which is then enhanced using natural language processing in Python. The process iterates until no new AOs are discovered.

Without using Python, but with the help of Thesaurus, we have compiled the initial SAO set. See the bold words in Table 10. When taking our technical innovation as Subject and simply refer to it as "material", three different main AO's can be identified, which is encapsulated in one sentence: "The material reflects pressure by changing colour through expanding silicone bulges". The primary purpose of the material is to make pressure visible. It achieves this goal through colour change. And the mechanism of the colour change lies essentially in the expansion of the silicone bulges. These become transparent, thereby revealing the material underneath.

The **morphology analysis** discusses also dimensions comparable to Bianchi et al. [2]. However, these dimensions are based on different frameworks, and manifest as shapes rather than responses to questions. Yoon et al. [23] explains that this morphology is structured based on the product hierarchical tree, which is created based on the physical and functional concepts of the technological product. These concepts are for example module, function, process, and physical structure. The dimensions of a product are established by an expert who has studied the hierarchical tree. This tree is developed from supporting frameworks such as F-term and TEMPEST. F-term is a system for classifying Japanese patents based on technical aspects. TEMPEST is a method that divides patents based on the viewpoints of Energy, Material, Personality, Space, and Time, with the initial letters forming the word TEMPEST. To find the shapes within the specified dimensions, text mining is employed. This is a process that transforms a large amount of textual data into structured data that can be analysed.

For the application of the morphology analysis, we did not use the proposed dimensions by Bianchi et al. [2], but instead formulated our own dimensions. To establish these, we examined which aspects of the material could be altered, still being a colour-changing material. This involved drawing from the literature review of the previous master thesis on Biomechanical Design, within which this material was developed. The dimensions in which the colour-changing material can be altered include: the stimulus, the type of colour change, material, flexibility, and the number of colours the material can change to (with 2 being the minimum, transitioning from red to blue and vice versa). The shapes of our case study, and therefore the morphology of the current design, are highlighted in bold in Table 11.

Table 9: Basic keywords

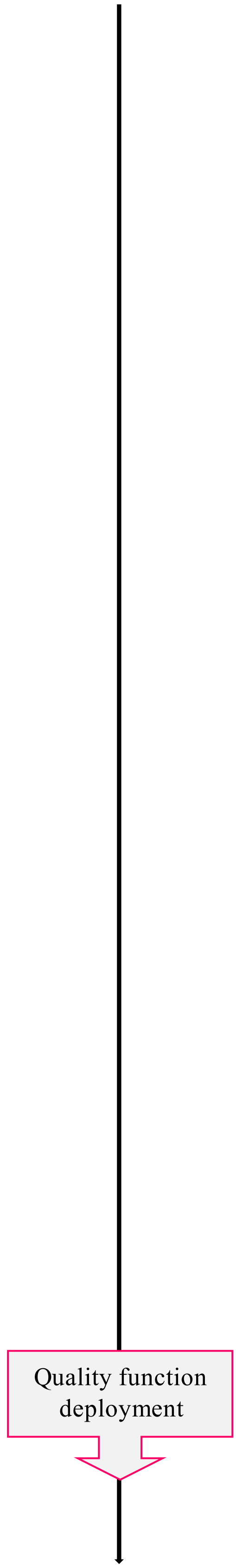
Category	Usage	Technology	Product
Keywords	Pressure sensor Colorimetric sensor	Stretching Flexible Colour change Color change Soft Expanding Transparent	Silicone Structured silicone Membrane

Table 10: AO set

Category	Target	Expanded	Output
Object	Force **Pressure**	**Silicone bulge** Polymerised siloxane Structure	**Colour** Color Colouration Coloration
Action	Sense Control Estimate Understand Intuition Become aware **Reflect**	**Expand** Swell Enlarge Inflate Grow Spread Dilate Stretch	**Changing** Shading

Table 11: Morphology of the case study

Dimension	Shape		
Stimulus	**Pressure** Thermal	Strain Chemical	Magnetic Hydrophilic (water absorption)
Type of colouration	Shaded	Uniform	**Gradient**
Type of colouration material	**Ecoflex 00-20** Carbon dots (CDs)	LED Thermochromic	Liquid Crystals (LCs)
Flexibility	**Flexible**	Soft	Hard
Amount of colours	**2**	3	



The **Quality Function Deployment (QFD)** cannot be executed as this is a customer-oriented approach that helps to find customer requirements, and thus the functional requirements. These found requirements state the characteristics a new product should have. QFD is often the starting point for roadmapping. However, this study is limited in its approach to the steps from a business perspective. There are no customers involved in this case, so the QFD will not be conducted.

4.1.2. Assessment approaches

Analysing all approaches, the first notable difference among the approaches to mapping the characteristics of a technology is that the technology description framework provides comprehensive answers to questions, thereby presenting a clear picture of the operation, appearance, and performance of the innovation, while the basic keyword set, the initial SAO, and the morphology analysis attempt to encapsulate all of this in short but powerful terms. If ultimately the function and operation are also clearly evident from these three approaches, then further exploration for other applications may not be necessary. Additionally, the basic keyword set, the initial SAO, and the morphology analysis in these cases serve as preparatory steps to a large-data analysis. The strict division between function and shapes based on a few words can help a lot in various text mining analyses. Although this is the primary purpose, this strict division also aid in determining the core of the technology, which may not immediately be evident from the technology description framework.

Whereas morphology analysis primarily focuses on the appearance and the functioning of the product, the basic keyword set and the AO set also examine how the product operates. The basic keyword set is centred around how the product is used and the underlying technology, but it presents this less clearly than the AO set. This is due to the generic categories that have been used. Normally, the advice here would be to adjust the categories, but the combination of the AO set and the morphology analysis describe the technological characteristics at both action and appearance level perfectly. Together, these two approaches suffice for the next steps in discovering new applications.

4.2. Generalise

STEP 2

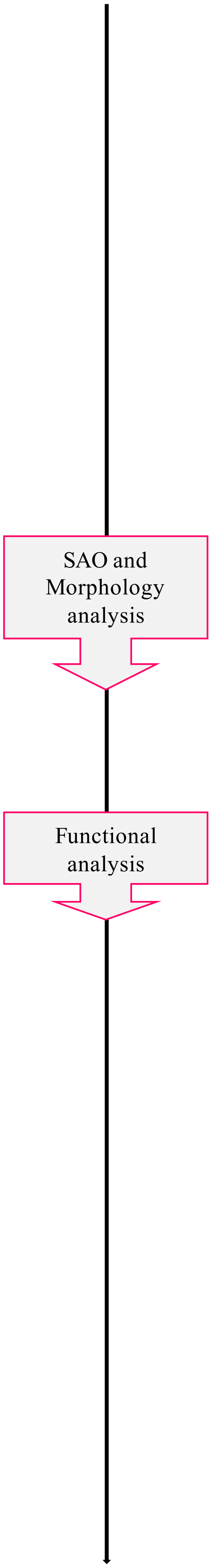
For the process of identifying problems for a technical solution, *generalising the functions of the technology* has been established as step 2. Within the literature, various approaches towards this step are delineated, which are:

- **SAO analysis (2/2).** Add synonyms to the functional descriptions of action-object to the previous stated initial AO [17, 18, 21].
- **Morphology analysis (2/2).** Add optional shapes to the previously stated morphology analysis [23].
- **Functional Analysis (FA).** The essence of the technology is determined by giving scores to a list of universal functions possessed by the technology [2].
- **Enabling functions (1/2).** Key characteristics are identified and descriptions are written down of what these characteristics enable [3, 14, 15].
- **Reframe solution.** The technology is viewed from a different technology field than its purpose technology field [3, 14, 15].
- **Compare solution.** The technology is compared with its existing competitors and it is checked if they share similar functions [3, 14, 15].
- **Emphasise descriptions of solution.** Multiple descriptions of the characteristics of the technology are analysed and checked which problem they could solve together or on their own [3, 14, 15].
- **Core-periphery analysis.** Preliminary research for finding technology convergence in which technological classes of patents are identified [25].

- **Lingo algorithm.** A clustering method for large data analysis and clusters patents based on common phrase discovery and semantics [30].
- **Technology performance map.** A clustering method for large data analysis and clusters patents based on their technology performance which is determined by 39 functional parameters of TRIZ [32].

In this section, the approaches are discussed, implemented when feasible and valuable and their results are assessed.

4.2.1. Implementation approaches



The approaches scaled under the second step within this research generalise the function of a particular technology in various ways. Some build upon the results acquired in step 1, while some approaches can be executed independently. By dissecting these approaches and juxtaposing their objectives and outcomes, we can discuss their relevance to this study.

Firstly, we examine the results of the **AO set** and **morphology analysis**, as highlighted respectively in Table 10 and Table 11. To generalise the function of the material, synonyms are explored in the case of expanding the AO set, and other shapes are considered in the case of expanding the morphology. When finding synonyms, Thesaurus and Chat GPT3.5 are used. To expand the AO set with other shapes, literature knowledge from the previous study in Biomechanical Design is consulted, which covers various colour-changing materials. The expansions of the AO set and morphology are found respectively in Table 10 and Table 11.

Another approach to generalise the function is proposed by Bianchi et al. [2] called the **Functional Analysis (FA)**, a TRIZ-based tool. The FA serves as a prerequisite for the Evolution Potential Analysis (EPA) to delineate the conceptualised technology across evolutionary trends. Following the methodology outlined by Bianchi et al. [2], the essence of the technology is determined by giving scores to a list of universal functions originating from the TRIZ theory. The essence of the technology resides in the set of functions possessed by the technology. The functional analysis assesses how well the generic functionalities acquired from TRIZ align with the technical innovation. A qualitative scale is used to assign scores to the functionalities: 1) A function receives the maximum score when it constitutes a primary function, distinguishing the technology from competing technologies, 2) A function receives a high score when it serves as a primary function, yet is also present in competing technologies, 3) A medium score is given when the function serves as a secondary function and complements the primary function, 4) The function receives a low score if it is not applicable to the technology.

In our case study, the technology of the lymphatic massage tool scores maximum on the function ‘To produce’. The tool produces colour, thereby distinguishing itself from all other tools serving the same purpose. Furthermore, this tool scores high on the functions ‘To bend’, ‘To prevent’, ‘To protect’, and ‘To remove’. The tool must be capable of aligning itself with irregular surfaces. In order to prevent lymph accumulation and thereby protect the human body from pain and discomfort, lymph should be safely removed. Medium scores have been assigned to the functions ‘To detect’, ‘To hold’, and ‘To orient’. The tool is used by the patient to detect the applied force and to orient whether the pressure is sufficient. The tool is small enough to be held in the hand, making it portable, yet is also holds itself in place during use. Thus, the general function 'To hold' can be viewed from two perspectives. The scores assigned to the key functionalities acquired from the TRIZ theory are presented in Table 12.

Table 12: Functional analysis

Function	Score	Function	Score
To absorb	Low	To freeze/boil	Low
To accumulate	Low	To heat	Low
To assemble	Low	To hold	Medium
To bend	High	To join	Low
To break down	Low	To locate	Low
To change phase of melts	Low	To mix	Low
To clean	Low	To move	Low
To cool	Low	To orient	Medium
To corrode	Low	To polish	Low
To decompose	Low	To preserve	Low
To deposit	Low	To prevent	High
To destroy	Low	To produce	Maximum
To detect	Medium	To protect	High
To dry	Low	To remove	High
To embed	Low	To rotate	Low
To erode	Low	To separate	Low
To evaporate	Low	To stabilise	Low
To extract	Low	To vibrate	Low

Solution mapping strategies

In addition to the fully structured qualitative techniques, the solution mapping strategy of Lee et al. [3, 14, 15] loosens the structure somewhat. In solution mapping four brainstorming approaches were suggested to explore the functions of a technical solution: (1) Describe **enabling functions** of the solution, (2) **Reframe the solution** using alternative perspectives, (3) **Compare the solution** to existing possible competitors, and (4) **Emphasise different or multiple descriptions of the solution** characteristics. In the first approach characteristics of the technology are identified and it is listed what these characteristics enable. A porous material for example enables to collect and retain a liquid. In the possession of the key characteristics from step 1, we will focus on this first approach.

From the TDF and the AO set, the key characteristics of the technology become clear. These are the characteristics that precisely indicate the capabilities of the material. In this case, that it changes colour, that the material is flexible, non-electronic, and activated by pressure. To generalise the capabilities and thus the function, each of these characteristics is generically examined for what it enables, in other words: what else the characteristic could be good for. In Table 13 the characteristics of this study case and what it enables are listed.

Table 13: Enabling functions

Characteristic	Changes colour	Flexible	Non-electronic	Pressure-activated
Enables	Signaling Playing Creating	Bending Conforming Rolling it up	Washing No charging Cost-effective Simple Reliable	Estimating pressure

Quantitative approaches

The latter three approaches, core-periphery, lingo algorithm and technology performance map, mentioned at the beginning of this chapter, follow quantitative methods. **Core-periphery analysis** forms the preliminary research for finding technology convergence, which will be discussed in step 3. In the study by Wang & Hsu [25], a patent citation analysis approach is employed to visualise "technological knowledge flow" networks from the collected data. Subsequently, the key technological classes within these patents are identified using betweenness and closeness centrality analysis. Additionally, a core-periphery analysis is used for the knowledge flow network to capture networks that may not immediately appear influential but have the potential to emerge in the future. **Lingo algorithm**, which is discussed by Li et al. [30], is also a clustering method for large data analysis. It creates relevant groups based on common phrase discovery and semantics. **Technology performance maps** cluster patents based on its name: their technology performance. This performance is determined by 39 functional parameters of TRIZ [32]. Due to the lack of composed large databases and the fact that the case study involves a single technology, all of these quantitative approaches are not implemented. However, these three quantitative approaches are classified under the function generalization step, as these groups are based on an extension of the original aspects of the technology. This extension also happens in the qualitative methods, but with words instead of clusters.

4.2.2. Assessment approaches

Within the conducted methodical approaches, the division lies in either carrying out the process individually or building upon the found results from step 1. The FA is a standalone approach as it operates from generic function rather than from the technology itself. However, it is recommended to have understanding of the working principle and the purpose of the technology, but this does not necessarily need to be articulated in words. In addition to the FA, also identifying enabling functions based on characteristics can also be executed without the execution of step 1. Note that the key characteristics appear easily from the TDF. On the contrary to these two approaches for the expansion of the AO set and the morphology step, the first step must be implemented to first establish the AO and morphology as it currently is, before generalising it.

4.3. Link

STEP 3

For the process of identifying problems for a technical solution, *linking functions to abstract problem applications* has been established as step 3. A crucial step because during this phase the function of the technology will be effectively translated into multiple problem applications besides its original intent. Within the literature, various approaches towards this step are delineated, which are:

- **Enabling functions (2/2) and use industry list.** A brainstorming exercise is conducted using an industries list with the enabling functions in mind, looking at where else the functions would add value and how [3, 14, 15].
- **Evolution Potential Analysis (EPA) in combination with catchword-based search.** The EPA identifies in which trends the technology is placed in the advanced stage of evolution to determine where the technology is ahead and therefore which catchwords will be used in combination with the technology's features and functions in a catchword-based search to determine next steps [2].
- **Innovation matrix.** Illustrates the relationship between the required availability of a technology and the uncertainty, meaning the feasibility of the technology [5].
- **Scenario field analysis.** An analysis wherein multiple potential future horizons are thought of and placed in a so-called scenario funnel [26].
- **PreFixSpan algorithm.** An algorithm that examines sequences within large databases [20].
- **Novelty detection technique.** An algorithm that examines sequences within large databases [29].
- **Associated Rule Mining (ARM).** A follow-up approach to the core-periphery analysis and a machine learning technique that is employed to identify interesting multi-technology convergence linked to the technology classes [24, 25, 27]
- **Linking grid.** Linking technology and product patents based on various matching relationships [23].

In this section, the approaches are discussed, implemented when feasible and valuable and their results are assessed.

4.3.1. Implementation approaches

This third step approaches will result in the potential applications for the colour-changing material case. The significant task of generalising the function to problem applications can be approached in multiple ways. By dissecting these approaches and juxtaposing their objectives and outcomes, we can discuss their relevance to this study.

When building upon **enabling functions and aligning the solution with broad industries**, a brainstorm could be performed as proposed by Lee et al. [3, 14, 15]. In this step, solution capabilities obtained from the previous step are aligned with the potential needs of various industries. This involves examining a list of possible sectors, which serves as a catalyst for identifying alternative solutions. This approach allows to broaden the perspective and consider diverse industries where the solution may provide value. The list provided by Lee et al. [3, 14, 15] with the industry sectors is given in Appendix B.

Solution mapping strategy: enabling functions

The brainstorm session, guided across various industry sectors, was conducted using the Artificial Intelligence (AI) tool ChatGPT3.5. Initially, we allocated 5 minutes to focus on the designated sector before consulting ChatGPT3.5. Using the AI tool we first described the material in a generic manner without mentioning its initial purpose, as outlined in the Section 1.1. Then the question was posed which applications such a material would have in a particular sector. After studying the proposed list from this

AI tool, we filtered the results for relevance or added applications inspired by this suggested list. Filtering in this step only involves removing any nonsensical applications or repetitions. Table 14 presents the brainstorming results from both our own engineering perspective and ChatGPT3.5.

Table 14: Brainstorming using technology sectors

Sector	Brainstorm results
Agriculture	1. Measuring force during milking cows 2. Monitoring plant growth 3. Animal collars or harnesses 4. Monitoring soil compaction 5. Fishing nets to manage the catches, reducing bycatch or overfishing
Mining	6. Monitoring pipeline stress with special coating, which could happen due to external factors like ground movements or external impact 7. Monitoring rock surfaces 8. Conveyor belts checking if maximum load capacity has been reached 9. Monitoring tunnel support systems to indicate potential instability (for example in bolts or lines)
Utilities	10. Integrate colour-changing material into insulators and power transmission equipment to monitor mechanical stress 11. Monitor cable tension and strain in telecommunications infrastructure 12. Cleaning wipes indicate when there is optimal pressure for cleaning
Construction	13. Window installation indicating when proper sealing is ensured 14. Monitoring stress in bridge construction in support structures or expansion joints 15. Tunnel support system 16. Monitoring stress in pipeline fittings 17. Roofing installation check 18. Stress flexures on critical points in building homes or scaffolding
Manufacturing	19. Packaging seals for food products 20. Bottle caps or seals to secure sealed bottle 21. Furniture joints or fasteners to indicate when the correct pressure is applied during assembly (Ikea?) 22. Molds that change colour when the material reached the desired shape/pressure 23. Joints during welding processes 24. Properly soldered or secured components on circuit board changes colour
Wholesale trade	25. Packaging materials 26. Integrate material into pallets, crates, or lifting equipment to check if maximum weight or pressure is reached 27. Detect product tempering by changing the colour of the seal when it is broken 28. Preventing counterfeit sales by having colour-changing labels to prove the product is genuine

Retail trade	29. Inspection stickers (for example for a vehicle) to indicate if the product went through inspection for safety standards etc. 30. Guide customer through assembly instructions by changing colour when they do the correct thing. 31. Lumber quality control 32. Medication compliance packaging (when the dosage has been taken, de material changes colour thus after dispensing medication from packaging) 33. Fuel pump handles to indicate when the handle is properly engaged 34. Clothing fit assessment (example clothes indicate the right size and fit) 35. Instrument string tension providing pitch accuracy 36. Use colour-changing material as display or attract attention
Transportation and warehousing	37. Cargo loading to provide visual confirmation of secure cargo stowage. 38. Material to indicate when secure connection between railcar couplers is established 39. Container loading 40. Colour changing straps or tie-downs to secure cargo 41. Seatbelt in car 42. Pipeline inspection (rep) 43. Safety harnesses in rollercoasters 44. Conveyor belt (rep)
Information	45. Book cover design (especially for childrens books) 46. Interactive movie posters 47. Interactive TV remote controls
Finance and insurance	48. Currency authentication (when pressure is applied to certain areas of the banknote, the material changes coour) 49. Credit card fraud prevention 50. Document authentication 51. Insurance policy validation 52. Passport authentication
Real estate and rental and leasing	53. Property security by incorporating the colour-changing material into doors, windows, sensors 54. Check tampered seals or labels (rep) 55. Seatbelts or airbag or other safety mechanisms check (rep)
Professional and technical services	56. Client engagement tool 57. Document verification (rep) 58. Structural health monitoring, when pressure or stress exceeds safety thresholds in buildings or infrastructure material changes colour (rep) 59. Interactive design elements
Management of companies and enterprises	60. Strategy visualization tools
Administrative and waste services	61. Clothing bins when full 62. Office supplies (stapler for example, colour changes during optimal pressure use) 63. Bin fill monitoring of waste reducing overflow 64. Compost monitoring, when pressure from composting activity reaches optimal levels, the material changes colour, indicating readiness for use as nutrient-rich soil amendment

Educational services	65. Textbook pictures 66. Puzzles (maybe a new picture dooms up when pressure is applied, another dimension is added) 67. Integrate the material into assistive devices or tools used by students with disabilities that they know they are using the devices correctly when the material changes colour. (Assistive technology) a. Adaptive gripping aids (for holding a fork, knife, spoon, pen) b. Orthotic braces (material changes colour when properly aligned) c. Sensory stimulation toys promoting engagement in therapeutic activities due to multisensory feedback. d. Prosthetic limbs (sockets can change colour when properly fit or not) e. Individuals with speech or communication difficulties could use assistive devices with colour-changing screens
Healthcare and social assistance	68. Blood pressure cuffs providing not only textual but also visual feedback 69. Medical adhesive bandages for wound care to prevent too much pressure 70. In walking aids to secure proper usage 71. Emotional support tools, promoting emotional expression and communication
Arts, entertainment, and recreation	72. Theatre seating (visible if seats are occupied) 73. Sport mats/balls to provide if technique is correctly performed 74. Theme park rides safety restrains (rep)
Accommodation and food services	75. Food packaging 76. Cooking utensils for chefs to use proper pressure during preparation
Other services, except public administration	77. Appliance repair tool, do technicians apply the correct pressure or torque? 78. Salon and spa equipment, used for beauty treatment or massage therapies. When therapists apply pressure during treatments, the material changes colour, providing visual feedback on pressure points and enhancing relaxation experiences for clients 79. Gym equipment, resistance bands 80. Colour-changing cleaning wipes (rep) 81. Child safety equipment, car seats or baby gates
Public administration	82. Government documents and certificates authentication (rep) 83. Law enforcement, handcuffs or restraint devices promoting safety during arrests 84. ID batches or access cards validation
Extra	85. Colour-changing shoe soles 86. Balloon changes colour before it pops 87. Funny stickers 88. Building toy to educate where weak spots are in building for maquette 89. Airplane pressure (inside) 90. Phone case 91. Bandage to monitor pressure 92. Dancing floor 93. Under water communication 94. Mattresses in stores to find perfect comfortable mattress or pillow

Evolution potential analysis

In addition to relying on cognitive knowledge, whether from an engineering perspective or using an AI tool, one can also search within patent repositories using a catchword-based search. Bianchi et al. [2] have conducted this, however, before this can be executed, the **Evolution Potential Analysis (EPA)** method must first be implemented. This follows the FA conducted in the previous section. Once the FA has been conducted, we gained a preliminary understanding of the abstract solutions of the technology. These solutions need to be translated into abstract problems. Bianchi et al. [2] accomplish this by identifying in which trends the technology is placed in the advanced stage of evolution. Within these trends, the technology is ahead, where the competition likely lags behind. Additionally, rapid response to the trend is crucial. This step constitutes the execution of the EPA method. EPA assumes that a technology always evolves along a defined path, shaped by a series of steps within a ‘Trend of Evolution’. The ultimate phase is ideality. The technology can be analysed along the 31 known TRIZ trends to determine its proximity to ideality.

Table 15 illustrates the stages per trend or evolution. To determine the stages, engineering knowledge was used, along with the example from Bianchi et al.'s article [2], where this method was applied to a cardboard material that absorbs impacts when used in packaging. From this example, it could be inferred what was meant with each trend of evolution.

Table 15: Evolution Potential Analysis

Trend of evolution	Stages of development	Case Study stage
Action coordination	1. Non-coordinated action 2. Partially coordinated action 3. Coordinated action 4. Action with intervals	1
Rhythm coordination	1. Continuous action 2. Pulsating actions 3. Pulsating action in the resonance mode 4. Travelling wave	1
Geometric evolution of linear constructions	1. Point 2. Line 3. 2D curve 4. Axi-symmetric 5. 3D curve	3
Mono-bi-poly-increasing differences	1. Similar components 2. Components with biased characteristics 3. Component plus negative component 4. Different components	2
Mono-bi-poly-similar objects	1. Mono-system 2. Bi-system 3. Tri-system 4. Poly-system	2
Mono-bi-poly-various objects	1. Mono-system 2. Bi-system 3. Tri-system 4. Poly-system	2

Space segmentation	1. Monolithic 2. Hollow 3. Multi-holed 4. Capillary porous 5. Porous with active elements	3
Degrees of freedom	1. Single degree of freedom system 2. Second degree of freedom system 3. Third degree of freedom system 4. Fourth (or higher) degree of freedom system	1
Surface segmentation	1. Smooth surface 2. Surface with protusion in 2D 3. Surface with protusion in 3D 4. Rough surface with active pores	2
Reducing system complexity	1. System at maximum viable level of complexity 2. One part per useful function 3. One part per main useful function	2
Geometric evolution of volumetric constructions	1. Plane 2. 2D curve 3. Axi-symmetric 4. 3D curve 5. Fully 3D	2
Customer purchase focus	1. Performance 2. Reliability 3. Convenience 4. Price	2
Reducing energy conversion n to 0	1. Several energy conversions 2. Reduced energy conversions 3. One energy conversion 4. No energy conversion	2
Controllability	1. Direct control 2. Control through intermediary 3. Addition of feedback 4. Addition of intelligent feedback	1
Market evolution	1. Commodity 2. Product 3. Service 4. Experience 5. Transformation	2
Webs and fibers	1. Homogenous sheet 2. 2D regular mesh structure 3. 3D mesh with fibers aligned according to load conditions 4. Active elements	2
Increasing use of colour	1. No use of colour 2. Binary use of colour 3. Use of visible spectrum 4. Full spectrum use	2

Dynamization	1. Immobile 2. Single joint 3. Multiple joints 4. Completely flexible 5. Liquid/gas 6. Field	4
Increasing asymmetry	1. Symmetrical system 2. Partial asymmetry 3. Matched asymmetry	1
Decreasing density	Scale from 10^4 to 10^{-3} kg/m^3	10^3
Reduced damping	1. Heavy damping 2. Critical damping 3. Light damping 4. Undamped	2
Decreasing human involvement	1. Human 2. Human + tool 3. Human + powered tool 4. Human + semi-automated tool 5. Human + automated tool 6. Fully automated tool	2
Non-linearity	1. Linear assumption of the system 2. Partial accommodation of system non-linearities 3. Full accommodation of system non-linearities	1
Macro- to nanoscale	Scale from 10^2 to 10^{-9} m	10^1
Boundary breakdown	1. Many boundaries 2. Reduced boundaries 3. Few boundaries 4. No boundaries	2
Design methodology	1. Cut and try 2. Steady-state design 3. Transient design 4. Slow degradation effects 5. Cross coupling effects 6. Design for 'Murphy'	2
Smart materials	1. Passive material 2. One-way adaptive 3. 2-way adaptive material 4. Fully- adaptive material	2
Increasing transparency	1. Opaque 2. Partially transparent 3. Transparent 4. Active transparent elements	2

Object segmentation	1. Monolithic solid 2. Segmented/Highly segmented solid 3. Solid granules/powder 4. Monolithic/segmented liquid 5. Aerosol/gas 6. Plasma/field	2
Increasing use of senses	1. 1 sense 2. 2 sense 3. 3 sense 4. 4 sense 5. 5 sense	1

Catchword-based search

Using the retrieved information from the FA and EPA Bianchi et al. [2] execute a **catchword-based search** to discover alternative technologies. This involves transforming the abstract problems into catchwords, which primarily consist of synonyms, nouns, verbs, and adjectives. Ultimately, a combination of these catchwords will need to be formed into a logical search string. It is recommended to have approximately 100 hits per query. Otherwise, the search term should be made more precise. The documents found form the so-called "idea pool". Experts can draw their ideas from this.

The final catchwords that can be used in a catchword-based search, derived from both the FA and EPA, can be found in Table 16. Most of these catchwords were copied from the table in Bianchi et al.'s article [2] as a material was used as example that had much similarity in some aspects to our case study's technology.

Table 16: Catchwords whereof most are retrieved from Bianchi et al. [2]

Selected general problem	Related catchwords
Functions	
To absorb (forces)	Sponge, damp, cushion, absorber, suck, imbibe, soak up, uptake
To bend	Flex, deform, curve, wrap, turn, bow, cover, reel, roll, wind
To prevent	Avoid, stop, halt, block, deter, inhibit, counteract, impede prohibit
To produce (colours)	Generate, create, manufacture, form, fabricate, develop, yield, make, construct
To protect	Guard, shield, screen, wall, shelter, defense, safe, armor, cap, net, security
To remove	Extract, eliminate, detach, clear, exclude, eradicate, expel, dispose
Trends of Evolution	
Geometric evolution of linear constructions	2D curve, straight, bent, spiral, curved, symmetry, contour, turn, bow
Space segmentation	Hole, pore, hollow, multi-holed, void, cavity, piercing, prick, punch, to drill, bore, split, tube, pipe
Dynamitisation	Joint flexible, liquid, gas, loosen, untie, adjustable, mobile, elastic

Quantitative approaches

The latter five approaches discussed in the beginning of this chapter are quantitative approaches. In the case of the PreFixSpan algorithm and novelty detection technique, both approaches involve examining sequences within large databases. Choi et al. [20] distinguish between two databases: the firm's own patents and a general database.

With the **PreFixSpan algorithm**, they can analyse the patterns that the firm's patents have gone through and how this aligns with patents from other firms that have undergone similar patterns, as well as the success of their subsequent steps. Within the **novelty detection technique**, the search for new patterns is conducted using structured keyword vectors per patent [29]. **Associated Rule Mining (ARM)** follows upon the core-periphery analysis. ARM is employed to identify interesting multi-technology convergence linked to these core-periphery technology classes. ARM is an unsupervised machine learning technique that comprises rules explaining how or why groups are or aren't connected. Technology convergence refers to the phenomenon where two or more existing technologies complement each other to form a hybrid technology [30]. The **linking grid** method involves linking technology and product patents based on various matching relationships [23].

All of these quantitative approaches were classified under step 3 since these methods reveal clear relationships and thereby potential applications or application fields. Due to the lack of composed large databases and the fact that the case study involves a single technology, these approaches are not implemented. We also mentioned the **innovation matrix** and **scenario field analysis** as possible approaches for step 3. However, these cannot be implemented for this study's case as these methods must be followed from a firm's perspective.

4.3.2. Assessment approaches

It was found that the brainstorming session using a list of industry sectors generated new applications directly. Especially with the assistance of ChatGPT3.5, an AI tool, this list could be significantly expanded. However, noticeable was that also the AI needed to be directed in this case and it was therefore helpful to have this industry sector list seen in Appendix B. It would be of added value to have the AI itself generate new industry sectors and hereafter devise new applications based on them.

Furthermore, this chapter has focused on preparing the catchword-based search. However, it has not been executed due to the cumbersome nature of this approach, and the already existing resulting list of applications acquired from the brainstorm. Particularly, the EPA method seems unnecessarily extensive, as the trends of evolutions and the related catchwords tend to lean more towards modifications to the material and thus finding new solutions rather than new applications. For instance, one could design a new colour-changing material based on gases or fluids using tubes for the displacement being inspired by Table 16.

A noteworthy observation is that the catchword-based search would likely have been deemed more crucial if the usage of ChatGPT3.5 was not feasible. This AI tool adds value to the execution of step 3. See Chapter 6 for an elaboration on the usage of an AI tool in combination with the proposed framework.

4.4. Choose

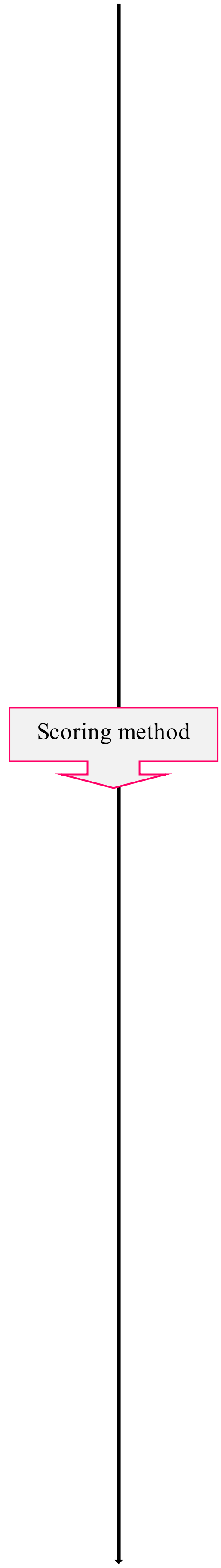
STEP 4

For the process of identifying problems for a technical solution, *choosing an application* has been established as step 4. Most application-finding processes discussed in the literature are already aimed at not only identifying applications but also focusing on the most promising ones during the function alignment with the potential problem applications. Especially in quantitative methods, there is consideration given to configuring the algorithm in a way that the application found is also feasible and successful. However, this is not always the case, and several qualitative approaches have been identified for selecting the most promising application:

- **Scoring method.** Different applications are evaluated against a set of technical and market criteria [2, 33].
- **Prioritise an industry sector.** An industry analysis is conducted to ascertain the sectors where the technology will thrive most effectively [3, 14, 15].
- **Portfolio analysis.** A firm's portfolio, i.e. its technology patents, is analysed to check which application for a technology fits best [5].

In this section, only the scoring method is implemented and the results are assessed. This study will not indulge in market research, and thus will not be able to prioritise an industry. Furthermore, portfolio analysis is particularly relevant when one aims to innovate from within a firm. Hence, we will not apply this approach. This section focuses on the scoring method.

4.4.1. Implementation approaches



For this fourth and final step, an application is selected. Given the qualitative nature of the outcome of step 3, the **scoring method** has been chosen for implementation.

The aim of the scoring method is to compare different applications by evaluating them against a set of technical and market criteria to determine which alternative applications are promising. The criteria are defined as follows: 1. Technical feasibility, 2. Market attractiveness, 3. Innovativeness. Typically, a firm's management will review the list of applications and assign scores to them within a short period of time. For technical feasibility and innovativeness, this study will assign scores from an engineering perspective.

In Table 17 the scores assigned to the results from the brainstorm are presented. The applications are rated with a number 1, 2, or 3 for technical feasibility, where 1 indicates that the application is not technically feasible, 2 indicates that a minor modification in the design is required, and 3 indicates that the material can be practically used immediately for the application. An asterisk is placed in the column for exceptionally innovative designs.

Table 17: Scores to brainstorm results

Brainstorm results	Technical feasibility	Innovativeness
1. Measuring force during milking cows	2	*
2. Monitoring plant growth	1	
3. Animal collars or harnesses	2	*
4. Monitoring soil compaction	1	
5. Fishing nets to manage the catches, reducing bycatch or overfishing	1	

6. Monitoring pipeline stress with special coating, which could happen due to external factors like ground movements or external impact	1	
7. Monitoring rock surfaces	1	
8. Conveyor belts checking if maximum load capacity has been reached	2	
9. Monitoring tunnel support systems to indicate potential instability (for example in bolts or lines)	1	
10. Integrate colour-changing material into insulators and power transmission equipment to monitor mechanical stress	1	
11. Monitor cable tension and strain in telecommunications infrastructure	1	*
12. Cleaning wipes indicate when there is optimal pressure for cleaning	3	
13. Window installation indicating when proper sealing is ensured	2	
14. Monitoring stress in bridge construction in support structures or expansion joints	2	
15. Tunnel support system	1	
16. Monitoring stress in pipeline fittings	1	
17. Roofing installation check	1	
18. Stress flexures on critical points in building homes or scaffolding	2	
19. Packaging seals for food products	1	
20. Bottle caps or seals to secure sealed bottle	1	*
21. Furniture joints or fasteners to indicate when the correct pressure is applied during assembly (Ikea?)	1	
22. Molds that change colour when the material reached the desired shape/pressure	2	*
23. Joints during welding processes	1	
24. Properly soldered or secured components on circuit board changes colour	1	
25. Packaging materials	2	
26. Integrate material into pallets, crates, or lifting equipment to check if maximum weight or pressure is reached	2	
27. Detect product tempering by changing the colour of the seal when it is broken	1	*
28. Preventing counterfeit sales by having colour-changing labels to prove the product is genuine	3	*
29. Inspection stickers (for example for a vehicle) to indicate if the product went through inspection for safety standards etc.	2	*
30. Guide customer through assembly instructions by changing colour when they do the correct thing.	1	
31. Lumber quality control	1	
32. Medication compliance packaging (when the dosage has been taken, de material changes colour thus after dispensing medication from packaging)	2	*
33. Fuel pump handles to indicate when the handle is properly engaged	2	
34. Clothing fit assessment (example clothes indicate the right size and fit)	1	*
35. Instrument string tension providing pitch accuracy	1	*
36. Use colour-changing material as display or attract attention	2	

37.	Cargo loading to provide visual confirmation of secure cargo stowage.	2	
38.	Material to indicate when secure connection between railcar couplers is established	1	
39.	Container loading	2	
40.	Colour changing straps or tie-downs to secure cargo	2	
41.	Seatbelt in car	3	*
42.	Pipeline inspection (rep)	1	
43.	Safety harnesses in rollercoasters	3	*
44.	Conveyor belt (rep)	2	
45.	Book cover design (especially for childrens books)	3	*
46.	Interactive movie posters	3	
47.	Interactive TV remote controls	1	
48.	Currency authentication (when pressure is applied to certain areas of the banknote, the material changes coour)	1	
49.	Credit card fraud prevention	1	
50.	Document authentication	1	
51.	Insurance policy validation	1	
52.	Passport authentication	1	
53.	Property security by incorporating the colour-changing material into doors, windows, sensors	2	
54.	Check tampered seals or labels (rep)	2	*
55.	Seatbelts or airbag or other safety mechanisms check (rep)	2	*
56.	Client engagement tool	1	
57.	Document verification (rep)	1	
58.	Structural health monitoring, when pressure or stress exceeds safety thresholds in buildings or infrastructure material changes colour (rep)	2	
59.	Interactive design elements	3	
60.	Strategy visualization tools	1	
61.	Clothing bins when full	1	
62.	Office supplies (stapler for example, colour changes during optimal pressure use)	2	
63.	Bin fill monitoring of waste reducing overflow	1	
64.	Compost monitoring, when pressure from composting activity reaches optimal levels, the material changes colour, indicating readiness for use as nutrient-rich soil amendment	1	

65. Textbook pictures	2	
66. Puzzles (maybe a new picture dooms up when pressure is applied, another dimension is added)	1	*
67. Integrate the material into assistive devices or tools used by students with disabilities that they know they are using the devices correctly when the material changes colour. (Assistive technology)		
f. Adaptive gripping aids (for holding a fork, knife, spoon, pen)	2	*
g. Orthotic braces (material changes colour when properly aligned)	2	*
h. Sensory stimulation toys promoting engagement in therapeutic activities due to multisensory feedback.	3	*
i. Prosthetic limbs (sockets can change colour when properly fit or not)		
j. Individuals with speech or communication difficulties could use assistive devices with	2	*
colour-changing screens	1	*
68. Blood pressure cuffs providing not only textual but also visual feedback	2	
69. Medical adhesive bandages for wound care to prevent too much pressure	2	*
70. In walking aids to secure proper usage	1	
71. Emotional support tools, promoting emotional expression and communication	3	*
72. Theater seating (visible if seats are occupied)	1	
73. Sport mats/balls to provide if technique is correctly performed	2	*
74. Theme park rides safety restrains (rep)	3	*
75. Food packaging	2	
76. Cooking utensils for chefs to use proper pressure during preparation	1	
77. Appliance repair tool, do technicians apply the correct pressure or torque?	1	
78. Salon and spa equipment, used for beauty treatment or massage therapies. When therapists apply pressure during treatments, the material changes colour, providing visual feedback on pressure points and enhancing relaxation experiences for clients	3	*
79. Gym equipment, resistance bands	1	*
80. Colour-changing cleaning wipes (rep)	3	
81. Child safety equipment, car seats or baby gates	2	*
82. Government documents and certificates authentication (rep)	1	
83. Law enforcement, handcuffs or restraint devices promoting safety during arrests	2	
84. ID batches or access cards validation	1	

85.	Colour-changing shoe soles	2	*
86.	Balloon changes colour before it pops	1	*
87.	Funny stickers	3	
88.	Building toy to educate where weak spots are in building for maquette	3	
89.	Airplane pressure (inside)	1	
90.	Phone case	2	
91.	Bandage to monitor pressure	3	*
92.	Dancing floor	3	*
93.	Under water communication	2	*
94.	Mattresses in stores to find perfect comfortable mattress or pillow	2	*

4.4.2. Assessment approaches

From the initial scores, it appears that creative solutions that are also technically feasible include: indicating the authenticity of a product as a label to prevent counterfeit sales, checking whether a seatbelt in a car or safety harness in the airbag is securely fastened, designing book covers, creating an emotional support fidget tool, applying appropriate pressure points during massage therapies, monitoring pressure as a bandage, and creating fun dancing floors.

The application "applying appropriate pressure points during massage therapies" is a highly significant outcome due to its resemblance to the initial purpose of this colour-changing material. The only difference is that the original purpose has been expanded to include the type of massage therapy, namely the MLD massage. This allows us to ascertain that the process works, with the limitation being the depth of the application.

4.5. Concluding remarks

This chapter has analysed the approaches for executing each step based on the requirements and the level of feasibility. Additionally, it examined the applicability of various approaches offered in the literature to the case study.

Step 1 is defined as *defining the technology characteristics*, encompassing five different categorised approaches from various articles. The TFD is used to describe and comprehend a technology, comprising a set of questions to be addressed. Moreover, the basic keyword set, SAO analysis, and morphological analysis have been conducted within this chapter. Although each of these approaches consists of short terms rather than lengthy answers, as seen in the TDF, it was concluded that when the core of the technology, i.e., its function and operational mechanism, is clear, this is adequate for the defined subsequent steps 2 through 4. It was found that the SAO analysis combined with morphological analysis proved to be the most effective.

Step 2 is defined as *generalising the functions of the technology*, transitioning from specified to generic functions. Four out of the ten approaches described in the literature for this purpose were executed within this chapter. Two of these approaches build upon the results from step 1, while the other two can be executed independently (although some knowledge of the technology is required). It was observed that the expansion of morphology is not particularly relevant for the subsequent steps of this process, as these expansions lead more to an alternative functional design rather than alternative applications of the function. However, the expansion of the SAO analysis is relevant, which reveals alternative function names that may be valuable in step 3. This also applies to the FA when the enabling functions of a technology are delineated. Apart from the morphological analysis, the other three executed approaches proved useful for the case study.

Step 3 is defined as *linking functions to abstract problem applications*. Again, multiple approaches are named as potential execution methods, but only three are performed. While building on enabling functions using broad industries yielded a lot of results from an engineer's brainstorming with an AI tool ChatGPT3.5. The EPA in combination with catchword-based search is considered less effective. The latter approach is cumbersome, difficult to grasp, and has not yielded inspiring results up until now. A real search with the discovered catchwords would still need to be conducted, but this was not done due to its complexity and the fact that it falls outside the scope of this study. The search would yield results in the form of articles, for which an almost new literature review should be executed. Additionally, EPA seems to focus more on changes within the technology design rather than inventing truly new applications for the existing technology as it is.

The final step, step 4, is defined as *choosing an application*. Among the three possible approaches, the scoring method seemed the best fit to our case study. The scoring method entails giving scores to the application list based on technical feasibility, market attractiveness, and innovativeness. Due to resource constraints on the economic front, ratings were given only for technical feasibility and innovativeness. This yielded interesting applications such as indicating the authenticity of a product to prevent counterfeit sales, checking seatbelt or safety harness fastening, designing book covers, creating emotional support fidget tools, applying pressure points during massage therapies, monitoring pressure as a bandage, and creating fun dancing floors. The application "applying appropriate pressure points during massage therapies" is particularly interesting due to its alignment with the original intent of this technical design, indicating the efficacy of following the approaches within the steps.

Now that we have gathered extensive information about the approaches regarding what is needed to execute them and how cumbersome they are, certain conclusions can be drawn related to, for example, which approaches should be performed sequentially and which type of processes are suitable for which types of situations. This line of thought will be continued in Chapter 5, where also a final framework, the product of this study and this line of thought, will be presented.

5

Framework development

In Chapter 4, the approaches for each step are explained and assessed, with some also being implemented. This results in a deeper understanding of the process and the requirements for each step and each approach. Next to this it can be derived how the approaches can be interconnected. This is relevant to the resulting product, i.e. a framework that can serve as a guideline in identifying applications for a technical innovation, this study aims to generate. This framework is the answer to the main research question: "How to identify alternative applications for a technical innovation?". This chapter will provide an overview of the mentioned approaches and place them in a diagram to identify gaps and discover new connections. Section 5.1 will elaborate on the overview of the approaches and how this results in the final framework with new connections, while Section 5.2 will delve into the practical implementation of the framework.

5.1. Final framework

Table 18 provides an overview of the discussed approaches in Chapter 4, and organises them in rows and columns. The four columns in the table relate to the four steps of the generalised proposed process of finding alternative applications for a technical solution. Each row represents a separate process as described in the literature. This makes it clear which approaches can be executed sequentially and which approaches do not yet have a clear previous or next step, indicated by an empty box.
A distinction is made between qualitative, quantitative and hybrid approaches. Even though we previously discussed only qualitative versus quantitative processes, we have found that some approaches for the steps within a process can be executed either qualitatively or quantitatively. We refer to these approaches as hybrid, and these are coloured orange in the table. Grey highlighted approaches are fully qualitative approaches, while blue coloured approaches indicate quantitative methods.

As stated, when approaches are next to each other in the same row, it indicates that they are described within the same process in an article and therefore it is recommended to execute these approaches sequentially. When examining the process and its associated steps presented by Bianchi et al. [2], there is referred to row C in Table 18. This process follows the following steps: (1) Technological Description Framework (TDF), (2) Functional Analysis (FA), (3) Evolution Potential Analysis (EPA) in combination with catchword-based search, (4) Scoring method. This process is clearly demonstrated in the literature by Bianchi et al. [2]. Although these steps are described in this sequence, the prior execution of these steps in previous chapter indicates that they do not necessarily need to be performed sequentially. Conversely, the Subject-Action-Object analysis and morphological analysis does need to be executed sequentially as these approaches were divided into two steps. In step 1, an initial SAO is established or the shapes of the technology's morphology are determined, which is then expanded upon in step 2. Therefore, it is not possible to deviate to another approach after completing step 1 in these cases.

In addition to the observation that some approaches can be executed independently while others cannot, we also identify gaps when filling in the methods in the literature in our determined process of four steps. Lee et al. [3, 14, 15] presented various brainstorming approaches to derive generalised functions. However, it lacked a defined starting approach in step 1, which is seen from row D-G. Although the key characteristics were necessary for identifying the enabling functions, these can for example be derived from another presented approach in step 1.

Furthermore, we placed the approaches Quality Function Deployment (QFD) and Scenario Field Analysis (SFA) totally over the first three steps. This is because these steps can ultimately result in a list of alternative applications, using the establishment of the technology's characteristics. The initiation of step 1 and the conclusion of step 3 are thus aligned with our proposed process. However, the intermediate steps are not explicitly defined and the result is not only a list of alternative applications. QFD is primarily employed as a technique used at the start of roadmapping [5]. Other steps of roadmapping did not provide added value within this overview.

Finally, it should be noted that the depth of the quantitative approaches is limited since they were not extensively executed in Chapter 4. We can only draw broad conclusions and therefore provide an overarching name for the various approaches within a step, such as *construct patent set based on technical innovation*, *clustering*, and *algorithm* for respectively step 1, step 2, and step 3. A patent set encompasses the characteristics of the technology and is thus associated with step 1. In quantitative analyses, clusters are created from patent and product data based on certain aspects, often revealing that technical characteristics appear in multiple places within the same function, which is related to step 2. And in step 3 an algorithm is typically applied to the clusters to identify relationships that elucidate problem applications. In step 4, no overarching name is used. This is because the choice of an application usually arises logically from step 3. The algorithm is designed to yield the appropriate promising application. Only in the case of the PreFixSpan algorithm will an evaluation need to be conducted eventually.

Where Table 18 provides an overview of the approaches associated with each step of the process,, Figure 11 illustrates the interconnections between these steps forming the final framework. Leveraging insights from the existing literature, identifying gaps within the overview, and employing logical reasoning, we have innovated and established connections between various approaches.

Within the depicted framework, the solid arrows represent the steps as they are found in the literature, while the dashed arrows introduce new possibilities. Due to these newly introduced paths the variability increases considerably. This framework, which is presenting multiple problem-finding processes, provides researchers and managers with an overview that can enhance the outcome of such research or reduce its costs. For instance, there may not necessarily be a need to apply an algorithm to an AO set or morphology set. Instead, one could effectively transition to a catchword-based search or guided brainstorming. This is also crucial for engineers who previously assumed they should always start with brainstorming. The establishment of an AO set or morphology analysis, alongside brainstorming, provides engineers with new tools to incorporate into their process.

Consciously, the overview and the created framework are juxtaposed in the next two pages to illustrate clearly how any gaps existing in the overview have been filled by new connections within the framework.

Table 18: Overview of approaches per step and their linkages

Process \ Step	1. Define technology characteristics	2. Generalise functions of the technology	3. Align functions with abstract problem applications	4. Choose application
A.	Quality Function Deployment (QFD)			
B.	Scenario Field Analysis (SFA)			
C.	Technology Description Framework (TDF)	Functional Analysis (FA)	Evolution Potential Analysis (EPA) in combination with catchword-based search	Scoring method
D.		Describe enabling functions (*BRAINSTORMING*)	Building upon enabling functions and align the solution to broad industries	
E.		Reframe the solution (*BRAINSTORMING*)		
F.		Compare the solution to existing competitors (*BRAINSTORMING*)		
G.		Emphasise different or multiple descriptions of the solution characteristics (*BRAINSTORMING*)		
H.	Basic keyword set			
I.	Initial SAO set	Create final AO set	Semantic analysis and outlier detection method	*ALGORITHM*
J.	Morphology analysis	Extend shapes of morphology	Linking technology and product morphology (linking grid)	*ALGORITHM*
K.	*CONSTRUCT PATENT SET BASED ON TECHNOLOGY INNOVATION*	Core-periphery analysis (*CLUSTERING*)	Associated Rule Mining (ARM) to find Technology Convergence (TC)	*ALGORITHM*
L.	*CONSTRUCT PATENT SET BASED ON TECHNOLOGY INNOVATION*	Patent-keyword frequency matrix (*CLUSTERING*)	Novelty detection technique (*ALGORITHM*)	*ALGORITHM*
M.	*CONSTRUCT PATENT SET BASED ON TECHNOLOGY INNOVATION*	Generating sequence database precedent enterprise (PE) (*CLUSTERING*)	PreFixSpan (*ALGORITHM*)	Evaluating next technology candidates on technological similarity and business stability
N.	*CONSTRUCT PATENT SET BASED ON TECHNOLOGY INNOVATION*	Lingo algorithm (*CLUSTERING*)		
O.	*CONSTRUCT PATENT SET BASED ON TECHNOLOGY INNOVATION*	Technology Performance Map (TPM) (*CLUSTERING*)		
P.				Portfolio analysis
Q.				Prioritising an industry sector

Legend

Text (grey)	Qualitative approach
Text (orange)	Hybrid approach (can be executed both qualitative or quantitative)
Text (blue)	Quantitative approach

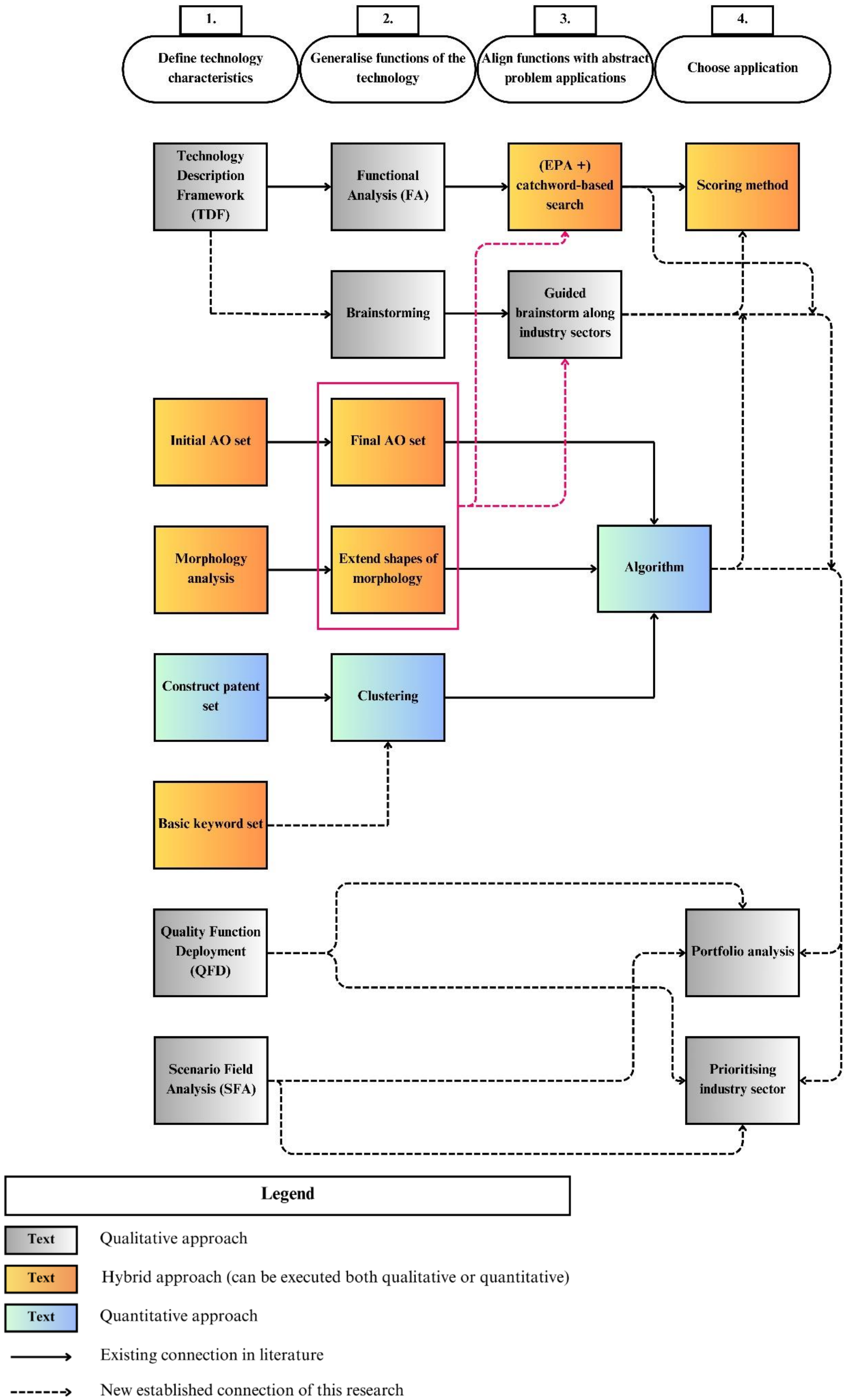


Figure 11: Framework MOT thesis

5.2. Practical implementation of the framework

It is suggested that when resources are limited, a qualitative approach should be pursued. Conversely, when a more comprehensive analysis is desired, one that is likely to be more reliable due to its reliance on prior existing literature and patents, a quantitative approach should be adopted. This implies that individuals or firms will need to follow either grey or blue blocks respectively within the framework. This section delves deeper into the practical application of the framework. Here, an initial distinction is made between three distinct main processes drawn from the framework outlined in Figure 11.

The first main process should be recommended when one possesses limited to no resources but still aims to bring their technical innovation to the market or desires to enhance their invention's value. This typically involves engineers with an idea or an SME. This process adopts a qualitative approach, focusing on a unique singular technical innovation and engages experts within various technical fields. Most outcomes from each step are achieved through brainstorming, also known as a disciplined application of imagination [35], and are therefore not empirically supported. Nevertheless, this process is effective in identifying alternative applications and can be executed relatively quickly. The recommended steps within this process are as follows: 1. Establish the initial AO set and conduct morphology analysis, 2. Expand the AO set and shapes of the morphology, 3. Conduct a guided brainstorm across various industry sectors, 4. Implement a scoring method. These steps can be entirely qualitative. However, it is possible to choose to modify one of these steps, for example, opting for a catchword-based search instead of a brainstorm.

A second main process is recommended when one has a substantial amount of resources in terms of time and money and aims to generate greater profits through market expansion or outsourcing their innovative techniques. In this case, the analysis can be based on a singular technique or on a comprehensive patent database of the firm to map out all possible options. Using algorithms in this process reduces the risk of failing when opting for market expansion, as it has been indirectly empirically proven in prior literature that a recommended subsequent action can yield success. However, this process is cumbersome and time-consuming. The recommended steps within this quantitative process are as follows: 1. Construct a patent set, 2. Cluster the identified patents into groups based on a dimension, 3. Apply an algorithm to the different groups to identify connections and differences and draw conclusions. Also within this process, adjustments can be made, such as establishing an AO set and using it for clustering patents.

A third major process is recommended for management teams seeking to innovate and chart a new direction for the firm. In this case, they prefer not to rely on experiences found in large databases but rather on their own and their customer's experiences. They are exploring potential product extensions, which are highly likely to lead to new applications and, consequently, new markets. Therefore, they are not specifically seeking alternative applications, but this could be the result. This process is time-consuming, but vital for each firm. This process does not delve into precise steps as it does not follow such a generic process as explained, but one method that can be used is the SFA followed by a portfolio analysis. Another option in this regard could be opting for a different method, such as QFD combined with prioritising a technology field.

All three main processes, their characteristics, and the situations in which they should be applied are described in Table 19. These three groups are also indicated within the framework depicted in Figure 12.

Main process	Characteristics	Situation	Example
I. Qualitative • Initial AO and morphology analysis • Expand AO and shapes of morphology • Conduct guided brainstorm • Scoring method	- Based on a singular technical innovation - Base is formed by knowledge on the technical innovation - Makes use of technical experts within different fields - Size of endeavour is adaptive, but it is possible to have results in a short amount of time. - Results are not empirically verified and stem directly from human knowledge. - Risk of failure is not minimised.	An entity with limited resources, yet possessing an innovative technical idea, seeking to establish a venture and ascertain the optimal product market fit or seeking to increase the invention's value when one already has a business.	A student invented a pressure-activated, colour-changing and flexible material inspired by the octopus and is seeking for promising applications that would increase this invention's value.
II. Quantitative • Construct a patent set • Cluster the patents based on a specified dimension • Apply algorithm	- Could be based on a singular technical innovation, but also on a firm's patent database - Base is formed by selecting a patent and literature set. - Makes use of technical experts within different fields in combination with large-data algorithms. - Size of endeavour is adaptive, but always cumbersome due to the use of algorithms. - Results are indirectly empirically verified as they stem from literature. - Risk of failure is minimised.	An entity with ample resources seeking to enhance the value of its products and generate profits by outsourcing its innovations expanding its market.	A large firm has been developing and producing pressure-activated, colour-changing flexible fabrics for decades, which are sold as fidget toys, then coasters and currently as pressure sensors in measuring pressure of prosthetics. Now, the firm aims to expand its market and explore where else this technology can be applied.
III. Management • Scenario Field Analysis or QFD • Portfolio analysis or prioritising a technology field	- Could be based on a firm's singular technical innovation, but also on a firm's patent database. - Base is formed by analysing the current market position of a firm's product (set). - Makes use of management experts. - Endeavour is time consuming. - Results can be empirically verified or not. - Risk is unknown.	A firm seeking to enhance its product foundation and customer satisfaction.	A firm that sells pressure-activated, colour-changing and flexible sheets knows that it has to constantly innovate, whether this is changing the design, manufacturing or application of their product, and is looking for promising approaches.

Table 19: Overview of main processes from the devised framework for finding applications

When seeking an alternative application and determining the appropriate approach, Table 19 can be consulted. One selects the most applicable situation in column 3. An example of such situations are given in column 4. Subsequently, a main process is described in column 1. If deviation from this process is desired, and one wishes to explore other options in following the process, the framework in Figure 11 must be consulted. The legend indicates which approaches are qualitative, quantitative, or hybrid. Because of the information given in Table 19, one should be conscious of the characteristics of qualitative and quantitative approaches and can thus decide how to deviate from the proposed main process.

5.3. Concluding remarks

In this chapter, we have synthesised all the information gathered thus far into a framework that not only delineates a problem-finding process in the form of four steps but also illustrates multiple paths for executing such a process. The choice of path depends on several factors, as discussed in Section 5.2. Three main paths are extracted from the framework with explanations provided regarding the types of situations wherein a path should be followed. Deviation from these paths is possible if desired. Notably from Chapter 4, our case study followed main path I. These steps were feasible for this specific case, and the described scenario in Table 19 closely resembles the current situation this research is aligned with. The characteristic of this path is that the risk of failure is not minimised due to the qualitative nature of the steps, as outlined in the literature. However, this study not only adopted an engineering perspective but also consulted Artificial Intelligence (AI), i.e. ChatGPT3.5 in step 3 of the process of guided brainstorming across industry sectors. It is anticipated that this decreases the risk of failure, given that AI can access and process an extensive amount of technical documents. As described in Section 3.4, this can reduce the uncertainty of failure, especially in combination with expert knowledge. Insights into the impact of AI on this framework will be discussed in Chapter 6.

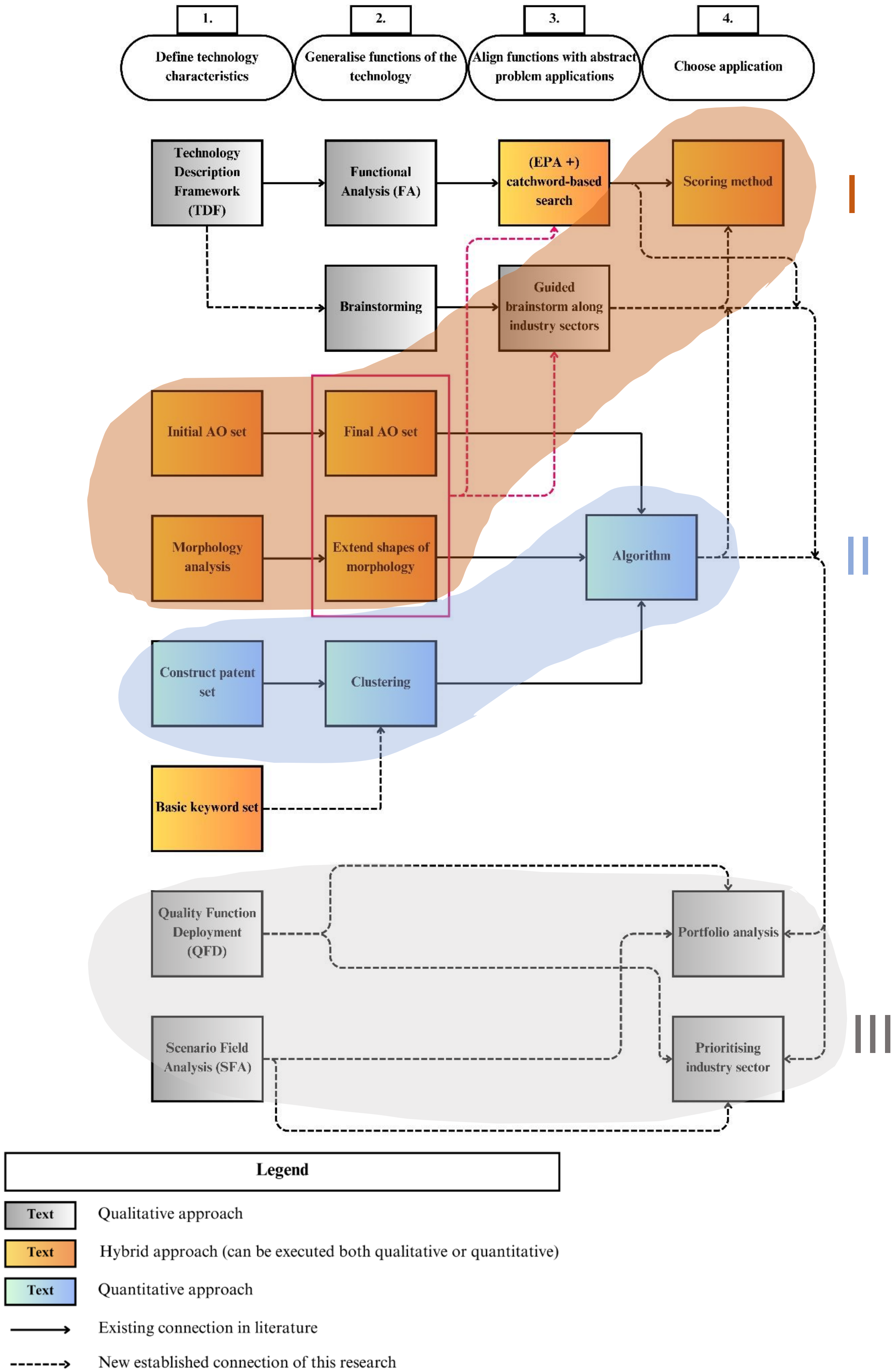


Figure 12: Framework MOT thesis with indicated main processes: orange, blue and grey coloured “bubbles”

6. Impact of AI on framework

As could be observed in Chapter 4, during the execution of certain steps, artificial intelligence (AI) was employed by consulting ChatGPT3.5. This usage was brief and no further explanation was given yet. ChatGPT3.5 served as a “creative collaborator” in select brainstorming scenarios [36]. In this study the guidelines and framework take precedence, and employing the case study for execution of the steps serves as a useful complement to demonstrate the resulting output. Acquiring this output, i.e. the execution of the steps, is not always paramount. Therefore we chose to use ChatGPT3.5 for time purposes. However, the necessities for executing a step are very important within the framework. The necessities determine the path one should take within the process which we have seen in Section 5.2. And as evident in the execution of the steps in Chapter 4, AI can be of much significance. It can make certain steps easier and less cumbersome given that fewer resources are needed, like having fewer experts present. The presence of accessible AI implies that the framework, as described in Chapter 5, can be approached differently. This upcoming chapter will delve into the impact of AI on components of the framework, thereby elucidating its influence on the overarching framework and highlighting considerations in the use of AI within this process.

The cumbersome aspects within the framework include the brainstorming sessions and the handling of patent data. The sections in this chapter will explore these aspects. The final sections will give a summary of the challenges of using AI regarding these aspects and suggests specific changes to the framework because of AI.

6.1. AI and brainstorming

Alex Faickney Osborn, one that introduced the term brainstorming first in the academic researches, defined the task as follows: “To practice a conference technique by which a group attempts to find a solution for a specific problem by amassing all the ideas spontaneously contributed by its members”, and also “the disciplined application of imagination”. He was one of the first to realise that AI could be helpful in a brainstorming process, particularly as a tool to overcome social barriers [35].

Some of the pillars of brainstorming is that it is done in a group setting, and criticism should be withheld to allow the creative flow to continue. Wild ideas should be encouraged. In the beginning the goal is to have a large quantity of ideas rather than quality ideas. However, Osborn argued that not everyone would freely express their ideas in an environment where judgement can occur. A set of rules is not always successful when one wants to overcome social barriers within a group. Hence, Osborn mentioned that using AI as a creative collaborator in a brainstorming session will enhance creativity. In 2022, an article supported this statement, as the results showed that a brainstorm session with a chatbot led to more ideas and greater diversity of ideas compared to a brainstorm session among humans [35]. An article by Habib from 2024 also supports this statement, this time focusing on the flexibility, fluency, elaboration, and originality of the resulting data [37]. Osborn’s ideology is that individual ideation (i.e., solo brainstorming) may even be superior to brainstorming within a large group. Solo brainstorming occurs less frequently within a large brainstorm session, yet it is crucial for the success of such sessions. This applies to brainstorming with AI as well: individual ideation remains important.

When used correctly, AI offers many profits. AI can enhance creativity by, for example, alleviating cognitive blockages through actively answering questions. It may even provide the first inaccurate or weird suggestion during a brainstorm session, which could relieve the participants from doing so. AI can process ideas in various ways, allowing for a different perspective to be adopted. Additionally, AI can assist in synthesising the generated content and identifying patterns that the human brain may not have identified as quickly [35]. However, there are also several challenges and ethical concerns. ChatGPT may exhibit biases due to certain training data. Also questions are raised about data privacy. Additionally, an AI chatbot can generate incorrect and misleading information. Furthermore, the AI bases its generated responses on pre-existing information, raising concerns about authorship and intellectual property rights. Next to this, it is also proposed that AI provides generic and safe answers, but these may not necessarily be feasible. The convergent aspect of idea creation, i.e. idea evaluation, may be less effectively addressed by AI. Consequently, individuals must strike a balance between innovation and practicality, or in other words: find a symbiotic relationship between human creativity and AI [36, 37].

The preceding section begins emphasising that AI must be used correctly. Due to the challenges and ethical concerns, a careful approach must be adopted when using AI in creative processes. It should be viewed as a collaborative creative agent rather than a replacement for the human brain. An AI will need to be guided, and next to this two critical phases of the creative process still need to be executed by a human expert: initiation and conclusion [37]. This approach is also pivotal for the individual and their confidence. Where AI encourages individual thinking, it should not take over the entire thought process. Doing so could actually stagnate the cognitive capacity of the human brain rather than enhance it, thereby reducing the confidence in later stages with cognitive fixation and reduced self-efficacy as result. The task of the individual engaging with AI in conversation will continuously involve individual ideation, as described by Osborn [35]. Evaluating the outcomes and making sense of them will be the responsibility of this person, who must also employ their self-regulated learning (SRL) skills and critical thinking to avoid losing sight of their goals and effectively monitor the process [36, 37].

6.2. AI and the patent field

Jiang and Goetz [38] discuss the impact of AI within the patent domain. While the initial purpose of documenting technological innovation and maintaining it within a database was to promote and regulate technological advancement, this interesting database has been used also for other purposes recently. The patent database is large-scale, but due to the structured factual content well-organised. This makes the database an ideal match for (large) language processing algorithms. While there are opportunities within patent research, challenges also abound. Jaing and Goetz review these opportunities and challenges by reviewing the latest developments of AI in the patent field.

They mentioned nine patent analysis tasks in their review: “subject classification”, “patent retrieval”, “information extraction”, “novelty prediction”, “granting prediction”, “litigation prediction”, “valuation”, “technology forecasting”, and “innovation recommendation”. While each of these tasks is interesting and a task such as subject classification is always necessary for patent analysis, there are three tasks that particularly align with the goal of this research, namely finding alternative applications. These tasks are novelty prediction, technology forecasting, and innovation recommendation. We summarise the findings of Jiang and Goetz [38] of these steps in this section.

6.2.1. Novelty prediction

An important task during the exploration of alternative applications is to analyse how novel and inventive these applications are. Assessing novelty can be conducted through various methods: indicator-based methods, outlier detection, similarity measurements, and supervised learning. This is indicated in Figure 13.

The indicator-based method uses preset indicators to compare new patents against old patents. Each indicator also includes a weighting factor, allowing certain requirements to be given more weight than others. However, this approach makes the analysis subjective, and the chosen indicators may not fully capture the nuances between highly innovative an cross-disciplinary innovations. Furthermore, there are various dimensions of novelty: novelty through recombination, novelty from technology origin, and novelty from a scientific perspective.

The outlier detection approach assumes that emerging innovations lie outside the landscape of existing patents. It entails the organisation of patents into groupings based on similarity, using numerical vector computations to identify patents deviating significantly from this established framework.

When one already possesses a patent, the focus shifts to similarity and the particular patent is subjected to comparison with an existing patent database. This also involves transforming patents into numerical vectors based on textual content such as abstracts, and subsequently comparing them. Lower similarity indicates a relatively new technology.

In contrast to the similarity measurement, the supervised learning approach uses trained models to fulfil similar objectives. It employs machine learning and deep learning models to establish text representations, and various network architectures. However, it is important to note that despite being designed to detect novelty, the model may compare the particular patent and the patent set on other features, as a deep learning model is somewhat of a black box [38].

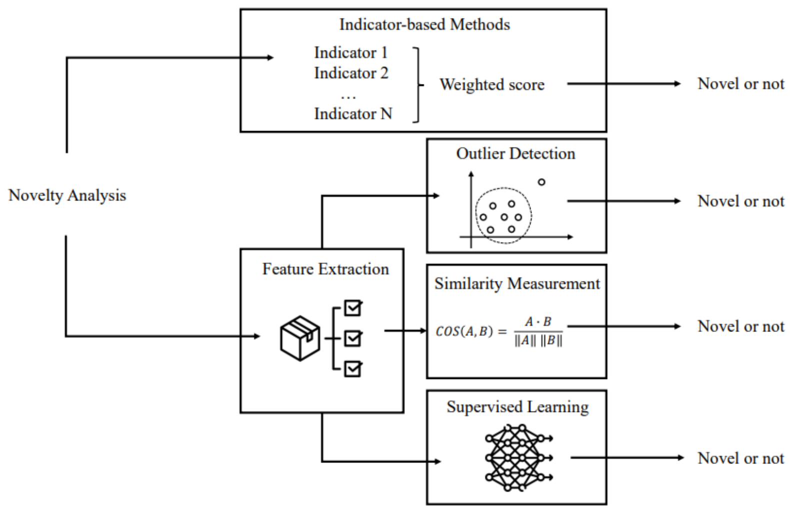


Figure 13: Methods of patent novelty analysis [38]

6.2.2. Technology forecasting

A patent analysis that aligns closely with our study, which we encountered within the literature as well, is technology forecasting. This approach aims to predict future technological developments based on existing patent information. As discussed earlier, this is of great importance for businesses, researchers, and policymakers. With knowledge of the direction of the technical innovation, design strategies and investments can be formulated accordingly. There are three distinct technology forecasting approaches: emerging technology forecasting, technology life cycle prediction, and patent application trend prediction. These are depicted in Figure 14.

Emerging technology forecasting concerns executing the binary task of determining whether a patent qualifies as an emerging technology or not. The challenging aspect lies in discerning the boundary between an emerging technology and one that is just on the edge of it. This fuzziness complicates identification and necessitates more sophisticated machine learning models. Training these models requires extensive datasets, rendering this task far from simple.

AI may also predict the life cycle of a technology based on patents. The typical phases of a technology life cycle include introduction, growth, maturity, and saturation. Knowing when a technology is in the saturation phase may indicate this technology could soon be replaced by another technology. Predicting the life cycle of a technology can thus play an important role in the strategic planning and market analyses of a firm. However, it is often not recommended to rely solely on patent analysis for this purpose, since social needs and user preferences should not be overlooked. A holistic approach is needed for a higher accuracy in determining the life cycle of a technology.

Patent analysis can also be used to predict trends. Based on these trends, firms can forecast potential collaborations with other firms, as well as identify potential competitors. Firms typically compare their own patent database with a public patent database to make predictions about the trajectory of their technologies. However, only a few articles have been published on this topic [38].

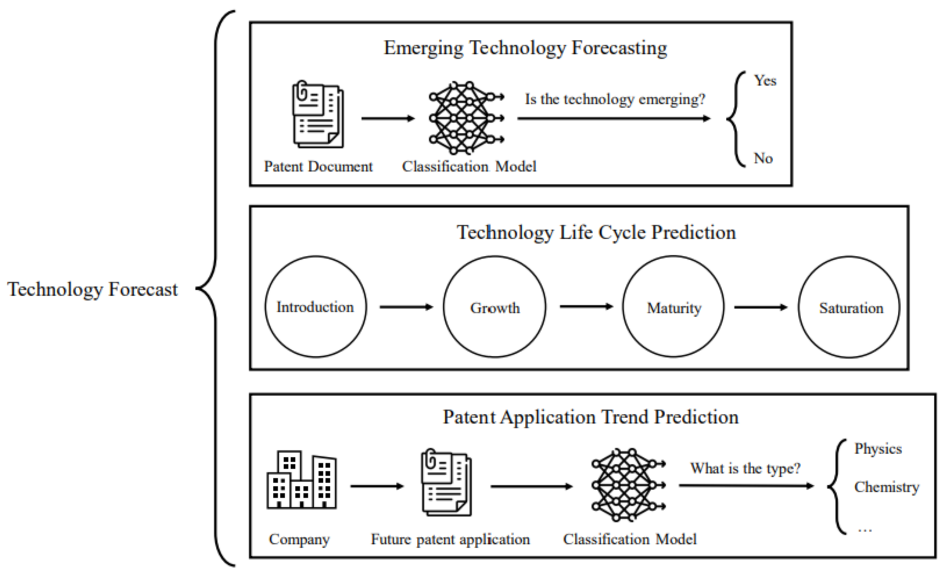


Figure 14: Specifics of technology forecasting tasks [38]

6.2.3. Innovation recommendation

The last discussed task that patent analysis can achieve is innovation recommendation. This aligns seamlessly with our study objectives. In addition to conducting analysis, it also provides necessary advice on future research and development opportunities, e.g. finding alternative application fields. When executed effectively, this can improve the competitiveness, efficiency, and user experience of a firm's technology. There are four methods to accomplish this task, also depicted in Figure 15: concept association analysis, technology gap detection, cross-domain analysis, idea generation.

In concept association analysis, the overall conceptual context of patents is examined, and new combinations are proposed. It is yet to be determined whether it is possible to look beyond simply combining certain features using only patent information.

Additionally, there is the method of technology gap detection. This method is interesting because it can extract information about what does not yet exist. Cross-domain analysis takes this further by linking patents across different technological domains. For example, it can determine whether a particular problem has been addressed within a certain field but remains unresolved in another domain. The identification of these gaps essentially entails finding alternative applications. However this analysis is challenging because different terminology is often used within specific domains. Due to the unique terminology, some connections may not be identified.

Finally, a GPT model can also be used to generate ideas. This is what was done in Section 4.3.1. Input instructions were provided to generate new ideas accordingly. This method can also be used to generate unique titles for patents and thus compile a set of patents [38].

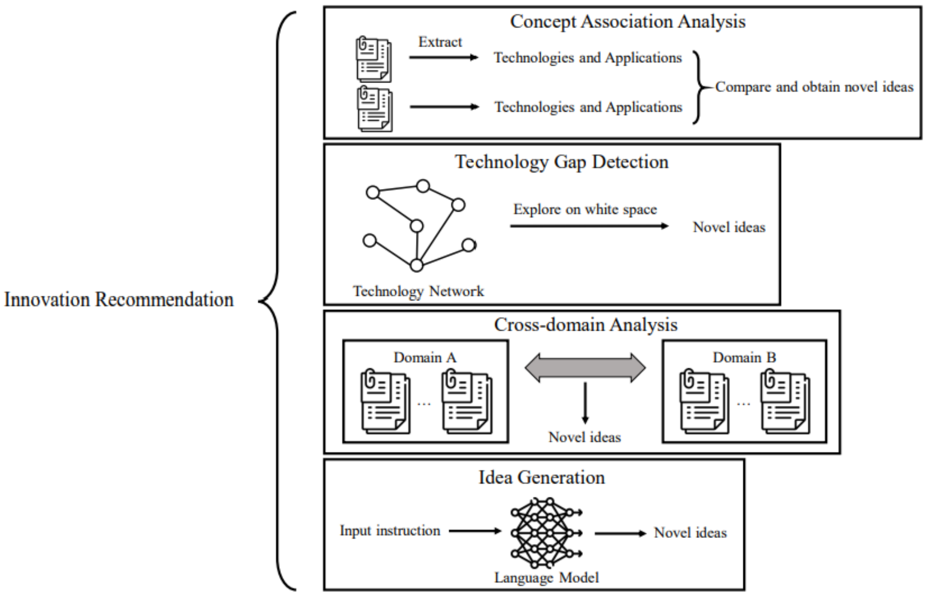


Figure 15: Methods of innovation recommendation task [38]

6.2.4. Challenges of using AI in patent analysis

Performing patent analysis using AI poses several challenges. Firstly, machine learning models require extensive amounts of pre-structured and pre-processed high-quality data to be well-trained. A difficult aspect with this is that most patents are not labelled correctly. Especially useful well-labelled public patent datasets are limited, which makes the training less advanced. Next to this, some studies resort to closed-source datasets, making it difficult to compare studies and outcomes and it compromises the reproducibility .

Additionally, another challenge arises in the use of language models. These large language models are preferred over other models because they can compare not only abstracts and other short texts from patents but also the overall descriptions, leading to more accurate results. However, many transformer models struggle to process such large amounts of text. Longformer was proposed as a long sequence modelling method, but it still was not able to process all long patent descriptions. The GPT-4 model seems promising as it can handle 32768 tokens, and may be capable of processing all patent descriptions, but it has not yet been used in existing patent analysis literature.

Another challenge in patent analysis is analysing the images within patents. Currently, patent analysis mainly relies on text processing, but images can also be compared. However, the existence of simple drawings and computer-aided design (CAD) drawings makes comparison difficult, especially since CAD drawings contain many lines, complicating the process. Nonetheless, many patents contain simpler drawings because inventors often prefer not to disclose more information than necessary. However, this raises again concerns about the content of the drawing and whether it contains enough information. Balancing these considerations presents a difficult challenge for AI. Ultimately, a hybrid method combining text and images may offer a promising approach to patent analysis. Although patent analysis appears to be a perfect match for a tool as AI, this research field is still underdeveloped in several aspects, requiring further research [38].

6.3. Summary of AI challenges and proposed usage in framework

Recently, more opportunities exists for individuals to use AI. Nevertheless, it remains to be seen when AI will have fully integrated into the process of identifying alternative applications. A general analysis was conducted on the use of AI in combination with brainstorming in creative process, of which the results can be applied within the framework depicted in Figure 11. Additionally, initial steps have been taken to use AI in the research field of patent analysis in combination with finding alternative applications. However, this field appears to be in its infancy due to the challenges that emerge. Drawing from the literature, we have identified several challenges associated with the use of AI in brainstorming sessions and patent analyses. These challenges are delineated in the first column of Table 20. In the second column, strategies derived from the literature are described to overcome these challenges.

While there are certainly challenges associated with the use of AI in combination with brainstorming, these challenges can be managed. For most challenges, it is imperative to maintain critical thinking, ensuring that entire texts are not simply duplicated and that the resulting outcomes remain sensible. Furthermore, it is essential within a creative process for individuals to take control of initiating and formulating the problem and actively guiding the AI towards the expansion of ideas. AI can be highly effective in the divergent aspect of idea creation. However, AI is simultaneously less effective in converging, as filtering requires rules, of which the expert often has greater knowledge.

We find the divergent aspect reflected in steps 2 and 3 of the proposed process within the framework, see Figure 16. In step 2, functions are generalised by finding alternative terms for specific function descriptions or by, for example, finding multiple shapes within the morphology of the technology. This step relies on the creativity of the mind and therefore depends on brainstorming with groups of experts. However, it can be significantly facilitated by AI when used in a hybrid form. Instead of requiring a group of different experts, this group will be replaced by an AI. It has been shown that using AI as creative agent in a brainstorm the creativity of the ideas increases. Next to using AI in step 2 it can also be used in step 3, when broadening the generalised functions to other industries. AI can be guided through the industries, as we have seen in Section 4.3.1.

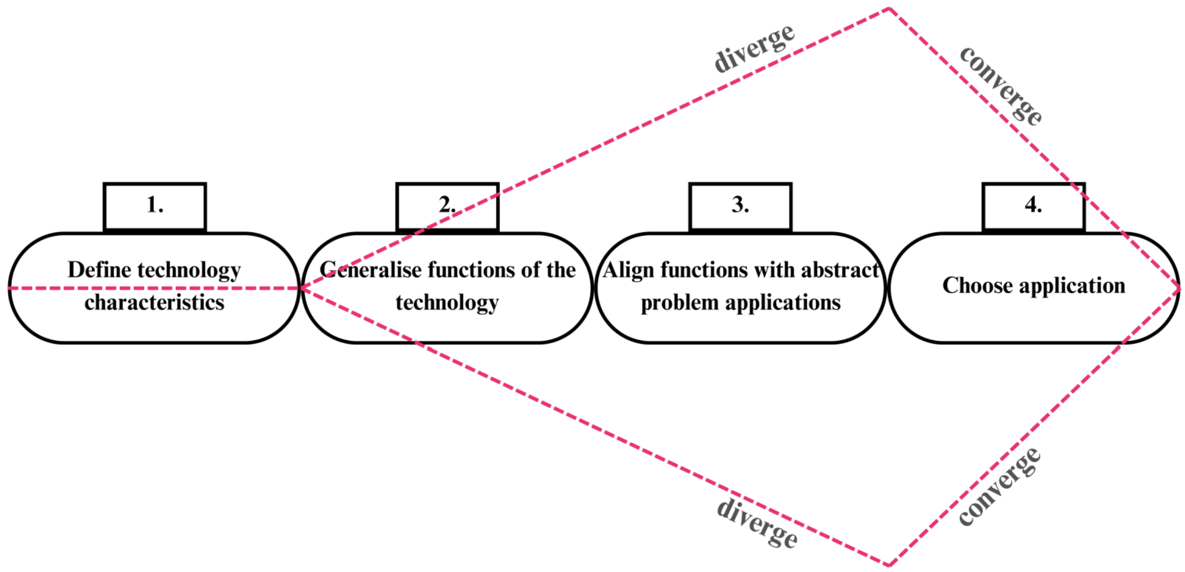


Figure 16: Indication of the diverging and converging steps within the problem-finding process

In step 2, we did not use AI but instead relied on our own engineering perspective and Thesaurus. However, in future iterations, AI could serve as a valuable creative collaborator in this regard. In step 3, we made use of the divergent aspect offered by AI by finding a lot of applications for each industry, using the function of the case study material in multiple ways. A brief description of the material's functionality – changing colour under pressure, flexible, and non-electric – was presented to the AI without mentioning its initial purpose – a tool that aids lymphedema patients. By subsequently posing a question to ChatGPT3.5 about how this invention could be valuable within a specific industry, lists of applications per industry sectors were generated. Focusing on finding applications within specific sectors did not provide the AI with complete freedom but did facilitate purposeful expansion of applications. Additionally, we remained critical and filtered out duplicates and impossible applications, while also brainstorming additional applications inspired by the AI's suggestions. Furthermore, ethical issues such as authorship were limited within this step since only short-term outputs were adopted.

We concluded that AI can be beneficial within steps 2 and 3 of the proposed process. This is because an expert is required for initiation and conclusion to provide definition to the characteristics of the technology (step 1), and for converging the results through for example the scoring method (step 4). Additionally, we conclude that AI should primarily be used within qualitative processes at the moment, rather than quantitative processes. For AI in combination with patent analysis, we namely encounter different types of challenges that cannot be controlled over at individual level. Addressing these challenges requires research and time to develop guidelines for handling them. In Figure 17, the framework is presented again, indicating the approaches where AI is currently well applicable, and thus which approaches, steps, and consequently which main processes AI may currently influence.

Table 20: Challenges of AI within the framework and accompanying guidelines

Challenges	Guidelines
Of AI and brainstorm	
• Biases due to training data • Data privacy • Incorrect and misleading information • Authorship and intellectual property rights • Less effective convergence in idea creation • Too broad or too shallow ideas • Stagnated cognitive capacity of the human brain	Critical thinking, apply self-regulated learning skills, and execute the initiation and conclusion by themselves with in between guiding the AI through short thinking steps.
Of AI and patent analyses	
• Deep learning algorithms are a black box, resulting in unknown biases and unknown reliability • Fuzziness factors due to qualitative definitions, resulting in biases • Different terminology use between patents of different fields, resulting in incomplete information • Limited well-labelled public patent datasets, resulting in incomplete information • Limited large language models, resulting in missing information • Improper image analysis in patents, resulting in incorrect information	Enhance large language models and image reading algorithms, while improving the structure and labelling of patent sets and make them publicly available.

Although patent analysis and AI seem to be a perfect match, this research field is still in its infancy, resulting in various challenges persisting and the results not yet being optimised. While AI tools will undoubtedly accelerate the quantitative approach, it will still be more cumbersome than the qualitative approach at the moment. Regarding the management approach (main process III), the influence of AI has not been considered. However, we can predict that the qualitative steps within this analysis can be implemented more quickly.

Ultimately, AI will influence the quantitative steps within the framework, but for now, the impact of AI is primarily on the qualitative approaches within steps 2 and 3 of the framework. This therefore mainly affects group I, as shown in Figure 17. Regarding Table 19, the characteristics of the qualitative process change, presenting an opportunity for SMEs and technical inventors. They become less dependent on technical experts, and by leveraging AI, they uncover much more potentialities, thereby minimising the risk of failure and the dependence on luck. Therefore, it is advisable to use brainstorming in combination with AI in a careful manner within the proposed framework depicted in Figure 11.

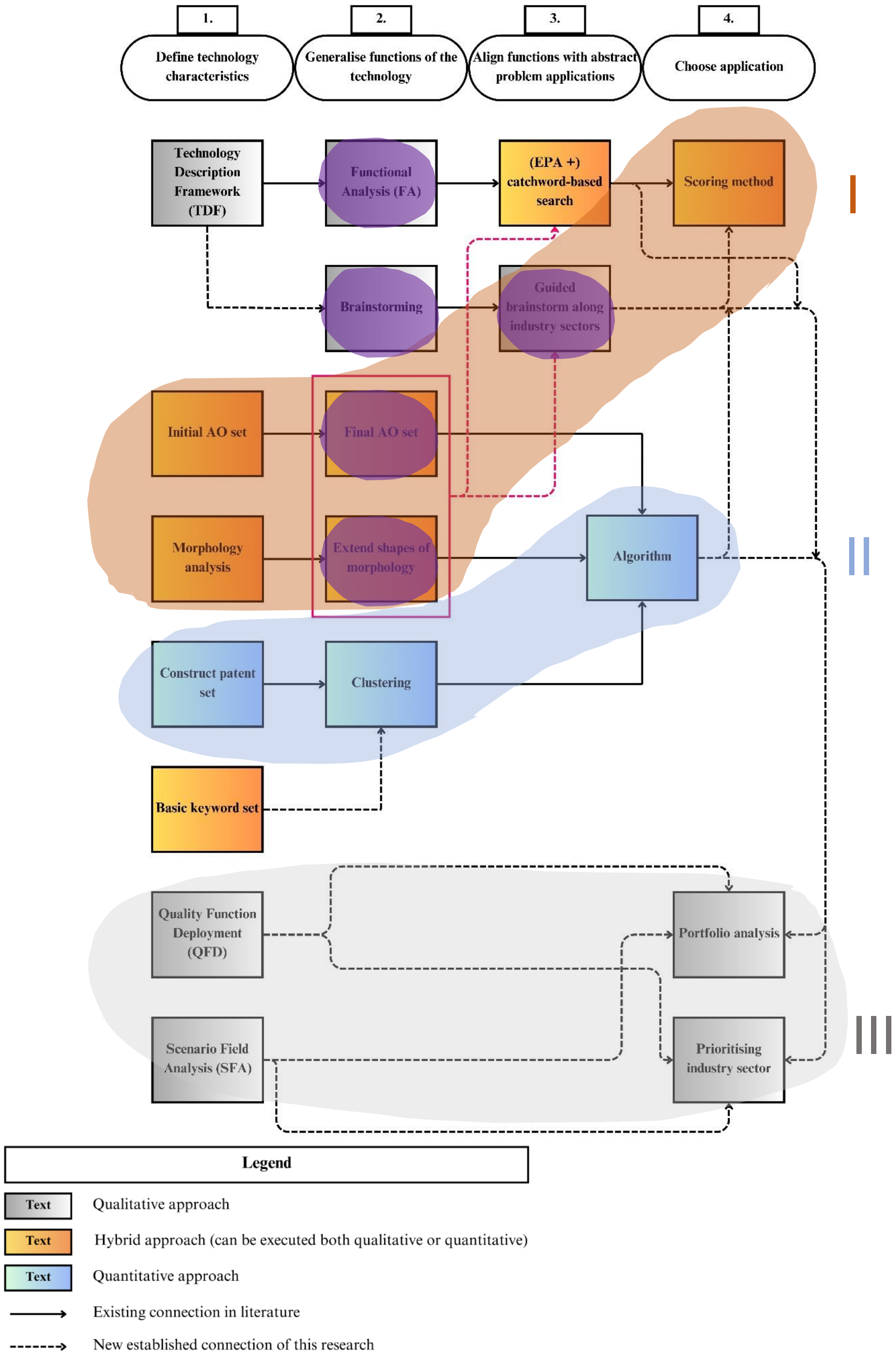


Figure 17: Framework MOT thesis with indicated main processes: orange, blue and grey coloured “bubbles”, and indicated AI influence: purple “bubbles”

7. Discussion

This chapter will discuss the findings of this study and how to implement these as business managers or engineers, elaborate on the managerial contributions, and reflect on the limitations while also advising future steps.

7.1. Findings

Within this study, the following challenge was addressed, which arose during research in the Biomechanical Design (BMD) field: devising a promising alternative application for an invented technical innovation. This previous research started with the assignment to mimic the changing of colours of the octopus within a flexible material. This task initially lacked a specific function. Through a brief brainstorming session from an engineering perspective, it was realised that various massage techniques rely on the effective application of pressure, suggesting the potential application of a visual feedback tool. Further exploration revealed that manual lymphatic drainage massage presents a unique case requiring a delicate balance between applying too much or too little pressure, often performed by a therapist. If patients can perform this time-consuming massage themselves instead of relying on a therapist, it would provide them with freedom over their time and treatment. This problem became the focus of the design process, and the design requirements were derived from this application. Consequently, while a particular design may initially appear suitable for a specific application, it may also offer solutions to other problems.

Whereas the BMD study focused on the design of the material rather than the selection of the function, this research aimed to concentrate specifically on identifying an application for a technical design. The limited time spent of engineers in seeking an application often results in many solvable problems going unnoticed. This study's literature research found that the issue lies in the difficulty to find these problems, whether the invention already has an application or no application at all. From our literature research, it emerged that while problem-solving methods are extensively discussed, problem-finding processes are scarcely addressed. Additionally, it was found that the systematic problem-finding methods that do exist are sparsely populated, unconnected and dispersed in separate groups within the literature.

For these sparsely populated articles, a solution was found in the approach of creating an overview of relevant literature. Initially, an preliminary research was conducted, wherein five relevant articles offering somewhat different perspectives on the problem-finding method were thoroughly examined. Subsequently, a systematic literature review with an accurate search term was carried out. This resulted in a low number of valuable articles, missing important informative articles found in the exploratory search. This indicated that we were dealing with a research field where one group dominates, while various different terms were used. We then tailored the search terms to focus on key terms, uncovering several additional relevant articles. This additional search term proved useful in yielding results that could ultimately be implemented in ResearchRabbit. Using ResearchRabbit, an artificial intelligence (AI) tool that illustrates interconnections between multiple articles, a scoping research was conducted. This tool clearly revealed a main group within this research field while also providing extra relevant articles. Through this literature approach, we were able to identify numerous potential tools and methods that could aid in establishing a generic process and guidelines for identifying alternative applications.

The existing tools and methods were difficult to unravel, and most of them do not seem applicable to a standalone, innovative technology. Therefore, we categorised the main components of such a tool or method. We defined four groups: (1) TRIZ, (2) Cognitive, (3) Roadmapping, and (4) Patent analysis. These groups are established based on the primary component addressed in these articles. By carefully analysing each of these groups and examining in detail the components of these methods, we were able to draw conclusions about the main process that should be employed in identifying alternative applications: (1) Define technology characteristics, (2) Generalise functions of the technology, (3) Align generalised functions with abstract problem application (fields), and (4) Choose application. The reversed TRIZ approach, cognitive methods and quantitative analysis delineated these main steps and various approaches to executing these steps. However, insights from roadmapping methods only allowed us to incorporate additional approaches under the defined four steps.

These four steps appear to be crucial for firms due to the relevance they bring in terms of increasing the value of a technical innovation. It is therefore questionable why there has not been a structured approach that presents multiple possibilities to achieve this objective. One assumption on this could be that such processes are mainly conducted within the confines of firm walls through traditional brainstorm sessions with experts and through other defined processes involving multiple forms of innovation disregarding the distinct aspect of finding only applications. Moreover, with the emergence of techniques like machine learning applied to patent databases, it seems that there is no longer a need for the “old-fashioned” steps. However, even this quantitative approach can certainly benefit by using these subsequent four steps.

Whereas a problem-solving method ultimately involves defining design requirements based on a function, this problem-finding process begins with defining the characteristics of the technology. This may involve describing the operation of the technology, outlining its primary function, and identifying the materials used, for example. In step 2, these characteristics are generalised, finding alternative names or "shapes" for them. For instance, expanding could also refer to spreading or dilating. In step 3, the alternative names for functions and different forms are linked to alternative contexts and industries, where different applications can be identified. In step 4, consideration is given to which application is most feasible and novel. However, additional requirements can be taken into account in choosing an application.

Within each step, multiple approaches have been discussed. As mentioned, in step 1, for example, one could focus on a single main function, the morphology, or the usage of the technology. Each approach can be executed to gain a clear understanding of the technology. However, it should be noted that it is important to strike a balance in the measure of understanding of the technology carried over to step 2. While excessive specificity may lead to narrow thinking, but less specificity may result in too many unrealistic applications. For instance, a brief functional description, such as “pressure estimation”, is mentioned in one of the early stages. While this provides direction for subsequent applications, it also imposes limitations. For instance, a colour-changing material could also be used as a fidget toy or art object. In this case, simply stating that the material is pressure-activated rather than capable of estimating pressure is sufficient. For our case study, it was found that an AO set and morphology analysis provided a description of the technological characteristics at both action and appearance level perfectly, without imposing limitations.

Next to prior notion regarding step 1, consideration should also be given to whether a technical innovation already has an application and whether it was designed for a specific problem, or if the technology emerged by chance and has no established applications yet. In most approaches described in the literature, among other the technology description framework and the subject-action-object analysis, the usage is mentioned, but one can determine the specificity themselves. As just described, it is even desirable not to be too specific and limit creativity in the next step. However, it should be researched what these boundaries are. A too broad description of the technology can also lead to too many possibilities that are not useful at all. An interesting mention in this regard is to think about how the AI technology could be described, and that when this input is used in the framework, the framework itself would emerge as the output, i.e. as the application.

After acquiring the four-step process, we examined the various approaches under each step and assessed whether they stood alone or were presented in a specific sequence. Table 18 provides an overview of the different approaches, with the four main steps indicated in the columns and the succession of approaches within the literature shown in the rows. Through the analysis of the different approaches, we were able to fill the gaps in this table by establishing new connections between the various approaches. This process resulted in the formation of the framework, as depicted in Figure 11. The solid arrows represent the process followed within a particular article, while the dashed arrows signify new connections and thus, new processes.

Within this framework, three main processes have been defined: the qualitative approach, quantitative approach, and management approach. These groups are illustrated in Figure 12, and explanations are provided in Table 19. It is recommended that when resources are limited, one should prioritise a qualitative process. Conversely, when a lot of time and resources are available, particularly for large firms, it is advisable to conduct a quantitative process. This is because it can be more reliable, as it involves working with actual patents, and a subsequent proposed step (e.g. investing in an alternative application) within a firm can be empirically validated if another firm has previously done so.

However, the possession of resources, such as knowledge and time, seems to become a less significant factor in choosing the appropriate problem-finding method with the rise of AI. This study delved into the use of AI within this framework and focused on its influence on qualitative brainstorming methods and quantitative patent analyses. It was concluded that despite the challenges presented in the literature regarding the use of AI in brainstorming, AI can be applied within the context of this framework with minimal risks. Ethical issues, such as authorship, are not addressed in the execution of a guided brainstorm with ChatGPT3.5, as the result is a list of applications rather than text. Furthermore, individuals can regulate whether the impact of AI in brainstorming will be beneficial. By adopting a critical and active stance, creativity can be enhanced and challenges can be overcome. However, this simple solution for using AI in brainstorming cannot be directly applied to AI use in patent analysis. These challenges are of a different kind and require further research to be minimised. This means that there is an opportunity for SMEs and technical inventors because they can conduct a problem-finding process with less risk of failure when leveraging AI.

By identifying the lack of a clear systematic process for finding applications for a technical innovation, we addressed the issue of scarce and scattered literature. By compiling the found tools and methods, gaps were illuminated in the conceived four-step process. We were able to establish new connections, resulting in the creation of a problem-finding framework. An added value to this framework is the publicly available ChatGPT3.5 within the qualitative brainstorming approaches, given the divergent nature of these. Within the initial and final steps, AI will not be valuable, as it may provide misleading information about a technical aspect and is limited in converging information, while the expert can explain the technology and establish criteria perfectly. Furthermore, AI will certainly make its entry into the quantitative part of the presented framework, but due to the accompanying challenges, it is not yet recommended to apply it.

Overall, a framework has been provided to assist both large and small firms or engineers in navigating the process of finding alternative applications for a given technology. Alongside, insights into the potential impact of AI are given to ensure the framework remains adaptable for the future.

7.2. Managerial recommendations

The research conducted in this MOT thesis holds great significance for technology managers and engineers, as it presents for the first time various tools and methods for identifying alternative applications for a technical innovation side by side in a framework, and also recommends a step-by-step process for different business scenarios. Additionally, the use of AI in combination with certain components of the framework is validated and recommended, thereby improving the ease and outcome of certain steps. It is recommended that firms employ this framework when they desire to increase the value of their technical innovation. When a technical innovation can address problems across multiple sectors, it can lead to widespread adoption of the product and thereby generate greater profits. Often, the issue did not stem from determining whether a product will fit in a specific market concerning a specific application, but rather from the process of identifying potential applications, which is solved with the presented framework in this report. The framework provides a structured approach to identifying possible sectors, thereby serving both large and small firms as well as technical inventors and entrepreneurs. In each of these business scenarios different paths within the framework are recommended. A distinction is made between three main categories: qualitative process, quantitative process, and management process.

A qualitative process is recommended when one possesses limited to no resources but still aims to bring their technical innovation to the market. This typically involves engineers with an idea or an SME. In this process, a unique technical innovation and experts from various technical fields are involved. The proposed steps initially involve establishing an initial SAO analysis to identify the main function performed by the technology, along with a morphology analysis. Subsequently, these function and morphology are expanded into generic and alternative terms. Following this, a guided brainstorming session is conducted to explore other applications, with specific sectors in mind. Finally, a scoring method is applied to select from the list of applications. In the diverging steps of this proposed process, AI can also be used provided that a critical mindset is maintained and AI limitations are addressed by posing specific questions.

A quantitative process is advisable when ample resources are available and there is a willingness to invest in a reliable procedure. Initially, a set of patents should be constructed, followed by clustering them into specific groups. An algorithm will then identify connections and differences between these groups, allowing conclusions to be drawn regarding technical inventions that are not yet present in certain sectors. While an overview of these steps is provided in this thesis, further refinement within the steps requires additional attention.

The third process is recommended for management teams seeking innovation and aiming to define a new direction for the firm. In this process, they rely on their own experiences as well as those of their customers. The outcome does not necessarily have to be an alternative application of a technology, although it can be. Two methods are presented in this study: scenario field analysis and quality function deployment. Both can be concluded with a portfolio analysis or by prioritising a technology field.

This study presents Table 19 as a guide for choosing which path to follow within the framework. One can select the situation that is applicable to them in the third column, and a generic process is proposed in the first column. If one wishes to explore other possibilities, the framework in Figure 11 should be consulted.

7.3. Scientific contributions

By introducing a new literature review method for scarce and scattered literature and by establishing a framework that presents multiple problem-finding tools and methods side by side for the first time along with their connections, this research makes a significant scientific contribution.

The literature review method within this thesis used in addition to the usual exploratory search, systematic search, and scopic search, a second tailored search term during the systematic search, and ResearchRabbit, an AI tool for visualising article networks during the scopic search. This approach to the literature review is unique and has yielded effective results.

The developed product of this research, i.e. the framework integrates tools and methods from other researchers and establishes new connections between them. These tools and methods have never been juxtaposed before or had new relations confirmed between them. Furthermore, these tools and methods are placed within a four-step process within the framework. These generic four steps are extracted from the literature to establish an overview of all the literature.

Additionally, consideration is given to the emergence of AI and its impact on the framework and the involved parties. There are perspectives on the use of AI in brainstorming and patent analysis, but integrating them into this framework immediately will ensure its future relevance.

As a final addition, a case study was used to validate most approaches within certain steps. For now, this means that the qualitative process within the framework has been validated. Moreover, the brainstorm with AI revealed that the initial purpose of the colour-changing material - providing visual feedback to lymphedema patients during manual lymphatic drainage massage - was broadly identified. An application that emerged was "applying the correct pressure during massage therapies." This suggests that the process is effective.

7.4. Limitations

The quality and comprehensiveness of the framework depend on various factors. Firstly, it became evident from the distribution of literature regarding problem-finding methods, that identifying every relevant method or tool would be challenging. Consequently, some relevant articles may have been overlooked due to the selection criteria.

Additionally, in an effort to generalise the process, every useful method and tool was attempted to be integrated into this proposed process of four steps. However, this approach may result in surface-level approaches, with limited depth explored, particularly in the quantitative approaches and management analysis methods. This limitation originated from the case study and the engineering perspective it required. An engineering perspective sufficed for executing the necessary approaches for the case study, purposely overlooking quantitative analyses. Although quantitative approaches are included in the overview and their contribution is evaluated, they are not actually implemented, thereby making the quantitative process unvalidated. While qualitative approaches have been validated, this validation is based on just one case study, necessitating repeated executions of these approaches to obtain reliable validation.

A limitation in this study is evident in the validation of the framework. In addition to the lack of applied quantitative analyses, AI could have been used in multiple instances, which was not done. For instance, ChatGPT3.5 could have been used to expand the SAO analysis and morphology analysis. Furthermore, ChatGPT3.5 could have autonomously generated new technical sectors within step 3, rather than solely focusing on the sectors presented in Appendix B. In step 4, alternative qualitative methods should be explored alongside the scoring method, as this is currently the only option provided. Additionally, the executed approaches were conducted from a single engineer's perspective, which introduces subjectivity.

Lastly, within this framework, there is no clear distinction made between starting with a technical innovation with an initial purpose, or whether the technical innovation has no application yet. There are approaches within step 1 that require this initial purpose to represent the characteristics of the technology. These approaches are not applicable for those who want to use this framework with a technical invention that may not necessarily serve any purpose yet.

7.5. Future research

In Figure 3, we depicted the progression of this research in the form of a pyramid. The empty space at the top, representing level 5, remained vacant. This signifies the future research need to validate the framework, implying that multiple technological innovations will need to be subjected to the framework. Additionally, changes occur within the levels of the pyramid over time. New relevant articles will emerge in the literature, necessitating a new literature review with updated search terms and selection criteria. Furthermore, focus should be placed onto the quantitative aspects of the framework. It should be checked whether the algorithms are sufficient to be applied. Next to this, it should also be explored in more depth to determine if quantitative approaches within this process can be executed qualitatively, thus making it easier for SMEs or engineers to implement. The influence of AI can also be investigated in this regard. This applies to the management process as well. When the framework changes due to critical insights and innovative technologies like AI, alterations occur within level 4 of the pyramid. Additionally, clearer distinctions can be made between the paths to be followed within the framework based on new insights. This includes indicating whether a path can be pursued with a technical innovation without any application. This study created the foundation of knowledge on finding alternative applications for a technical innovation. Future research focusing on the above remarks could lead to the pursuit of a complete and validated framework accessible to every individual, filling in the empty space at the top of the pyramid.

8.

Conclusion

This study presents the development of a framework designed to serve as a guideline for entities seeking alternative problem applications for their technical innovations, thereby possibly enhancing the value of these innovations. This framework serves as the answer to the main question “How to identify alternative applications for a technical innovation?”. Additionally, this study provides insights into the research field concerning problem-finding methods and the various challenges associated with it. It is concluded that the process of identifying alternative problem applications consists of four generic main steps: (1) Define the technology characteristics, (2) Generalise the function of the technology, (3) Link the generalised functions with abstract problem applications (fields), and (4) Choose an application. Within these four steps, various approaches could be used. Some approaches in step 1 naturally lead to a particular approach in step 2. Some approaches are covered in the overall article but could be placed under one particular step, while others did occur in a full process within an article but can be used independently. Based on these insights, connections have been drawn between multiple approaches, thus identifying multiple paths to conduct the problem-finding process. Recommendations have been provided on following a certain path within the framework based on the resources available to the entity and the level of risk the individual is willing to undertake: a qualitative approach when resources are limited and risk-taking is acceptable, and a quantitative approach when ample resources are available and uncertainty is desired to be minimised. However, when willing to use an AI tool such as ChatGPT3.5, the risk in the case of the qualitative approach can be mitigated. This study employed a pressure-activated, colour-changing, and flexible material as a case study. Various approaches under specific steps were executed and therefore validated using this example in Chapter 4. From the followed process using the case study, an application emerged that almost resembles the initial purpose of the colour-changing material: “applying appropriate pressure points during massage therapies”. This demonstrates a validation of the qualitative process. A conclusion that can be drawn for our technical innovation, and therefore a standalone technical innovation conceived by an individual engineer or SME, is that a qualitative path within the framework should be followed with the AI tool ChatGPT3.5 as creative collaborator. The framework established within this study serves as a basis for firms and engineers to find a method to devise alternative applications to their technical innovation, and is paving the way for an innovative framework that integrates AI. Frequent use of this framework could potentially lead to increased communication between technical sectors, resulting in faster resolution of issues within these sectors.

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Appendix

A. Quantitative methods

OuYang & Weng, 2011	Geum et al., 2013	Kim et al., 2013	Lee at al., 2014	Yoon et al., 2014
1. Industrial analysis and patent search strategy • Industrial analysis and expert interview • Patent search strategy **2. Selecting industry basic patent and building patent family** • Industrial basic patent set • Candidates of patent family • Constructing patent family **3. Selection key patent** • Computing key patent priority number • Scree test • Key patent **4. Key patent citation** • Two-step patent citation • Candidates of key technology patent • Key technology patent **5. Technology performance analysis** • Analysis of patent technology performance • Transformation by TRIZ 39 parameters • Implementation of technology performance map	**1. Data collection and preprocessing** • Collecting the patents • Constructing the patent-keyword frequency matrix **2. Novelty detection** • Conducting novelty detection technique • Identifying the novel patents	**1. Identification of a pair of technology groups** • Clustering of patents into *k* technology groups • Selection of two technology groups that may provide technology convergence (TC) • A patent citation network is set up and input for the next step. **2. Selection of a pair of core patents** • Selection of *m* core patents from each selected technology group • Selection of two core patents that may provide TC **3. Exploration of potential TC** • Extraction of representative keywords from selected patents using textual data • Exploration of TC using combined representative keywords	**1. Data collection** • Process: Construct a set of patents including potential technological opportunities • Method: Two-stage patent citation analysis and Keyword search **2. Expert-based basic opportunity identification** • Process: Construct a technological attribute-application table and Identify basic opportunities • Method: Experts judgments and Multiple keywords matching **3. AO-based opportunity augmentation** • Process: Construct an AO set and Identify augmented opportunities • Method: Iterative AO (action and object) structure text mining **4. Technology opportunity identification for a SME** • Process: Match a SME's existing technology with basic and augmented opportunities • Method: Multi-keywords/AO matching	**1. Data collection** • Selecting existing technology • Collecting patents **2. Structuring Technology morphology** • A Morphology Analysis (MA) is executed, where first, the fundamental function of the subject are defined. In this step, the features of the subject are broken down into several attributes. • The next step is to list all possible levels in which each attribute can manifest itself. • Third, all combinations that can produce unique sets of levels are investigated. • Fourth step is to attempt to find practical instances for each combination. The final step is to eliminate the infeasible combinations and list the reamaning combinations in order of importance. • Supporting methods for MA such as text mining, F-term, and TEMPEST are utilized to minimize the dependence of expert's intuition. **3. Structuring Product morphology** • The product morphology is separated into three groups: existing product, applied product, heterogeneous product. **4. Linking between Technology & Product morphology** • Relation analysis is used. • Participation of expert **5. identifying technological opportunities** • Technological opportunities are identified.

Yoon et al., 2015	Seo et al., 2016	Choi et al., 2019	Li et al., 2019	Wang & Hsu, 2023	Wang & Lee, 2023

1. Set up a TOD knowledge base
• Stores the functional information of products and technologies
• Structures the relationships of product, technologies and their functions by proprocessing large-scale patent data over a wide range of technical fields.
• Extract the function related to prodcuts from patents using NLP
• Identify technologies that are represented with a set of relevant functions, and relate the technologies to their products
2. Follow TOD logic paths
• Explore the potential opportunity taking into consideration the given ETPs
• Find the functional similarities
• Identify the Technology or Product opportunities
	1. Extracting product information
	• The product information is extracted from patent database using text mining technique
	2. Generating association rules
	• Association rule mining (ARM)
	3. Identifying product opportunities taking into account a firm's internal product portfolio by measuring potential value of product opportunities
	• Exploring the novelty of potential products uncovered by the association rule
	• Measuring the potential value of product opportunities. For the potential value, we present an evaluation indicator reflecting 3 aspects:
	  ○ The confidence measure of the association rule
	  ○ The importance of the conditional products in a target firm
	  ○ The importance of the consequent products in all the other firms except the target firm.
		1. Generating a sequence database using PEs' patents information
		• Frequent length-1 sequential pattern of the target firm
		2. Exploring frequent sequential pattern and discovering subsequent technology candidates
		• PrefixSpan algorithm
		• Five indicators (PI, CTSI, CR, TCI, RI)
		3. Evaluating next technology candidates on technological similarity, business stability, and recency
		• TOPSIS method
		• Appropriate opportunity technologies with less uncertainty for the target firm
			1. Retrieving and collecting the data
			• Use different search queries related to the subject of the study in Web of Science and Derwent Innovations Index (DII)
			2. Preprocessing the obtained data
			• Divide papers and patents by year, and remove the noise data
			• Convert the papers and patents in text format compatible for text mining
			3. Clustering topics with the Lingo algorithm
			• Generate technology topics with the Lingo algorithm that uses the vector space model (VSM) and the singular value decomposition (SVD)
			• Assign labels to the conceptually varied cluster labels
			In short: phrase extraction, cluster-label induction, cluster-content allocation
			4. Generating the hierarchical structure of the technology
			• Clustering results is objective evidence for decision-making
			• Include domain experts' knowledge for topic analysis and the construction of the hierarchical structure
			5. Constructing the maps of the technological evolution based on scientific papers and patents
			• Domain experts and one associated professor organize the Technology RoadMapping (TRM) panel to construct the map of the evolution
			6. Forecasting the technology trends
			• Carry out the differences analysis of the first appearance of the technical topics and the differences analysis of the technical topics
			• Compare the two gaps and combine them with the detailed path of the technology evolution
				1. Construction of TKF network
				• Network theory
				• Patent classification scheme
				2. Dynamic critical technology analysis
				• Betweenness centrality
				• Closeness centrality
				3. Identifying emerging technology classes
				• Core-periphery analysis
				• Four emergence indicators
				4. Mining multi-TC patterns with emerging technology classes
				• Association rule mining
				• Four interestingness measures
					1. Construction of TKI network
					• Network theory
					2. Link analysis and feature extraction
					• Local, global, quasi-local, and network centrality link prediction measures
					• Principal component analysis
					3. Link prediction model building and validation
					• Support vector machine
					• Random forests
					• Back-propagation neural networks
					4. Technology convergence prediction and analysis
					• Link prediction model
					• Patent landscape analysis
					• Edge betweenness analysis

Li et al., 2023

1. Data collection and preprocessing

- Develop the query of patents and scientific papers
- Data collection
- Data preprocessing

2. Extracting technical topics from scientific papers and patents using SAO semantic mining

- Extracting SAO structures from patents and from scientific papers
- Calculating the similarities of SAO structures
- Calculating the similarities between the patents and between the papers
- Clustering topics with MDS year by year
- Identifying first-level technical topics of patents and of papers
- Identifying second-level technical topics of patents and of papers

3. Detecting outlier scientific papers using outlier detection method

- Obtaining the distribution of scientific papers in 2D space with MDS
- Perform KNN, LOF, Iosolation Forest
- Identifying outliers in scientific papers

4. Identifying technology opportunities using gaps analysis

- Perform: The analysis of gaps between second-level technical topics of scientific papers and patents; The analysis of gaps between topics of outlier scientific papers and topics of patents; Expert knowledge
- Identify technology opportunities

B. Industry sectors

AGRICULTURE, FORESTRY, FISHING AND HUNTING
Crop production
Animal production and aquaculture
Agriculture and forestry support activities

MINING, QUARRYING, AND OIL AND GAS EXTRACTION
Oil and gas extraction
Mining, except oil and gas
Support activities for mining

UTILITIES
Utilities

CONSTRUCTION
Construction of buildings
Heavy and civil engineering construction
Specialty trade contractors

MANUFACTURING
Food manufacturing
Beverage and tobacco product manufacturing
Textile mills
Textile product mills
Apparel manufacturing
Leather and allied product manufacturing
Wood product manufacturing
Paper manufacturing
Printing and related support activities
Petroleum and coal products manufacturing
Chemical manufacturing
Plastics and rubber products manufacturing
Nonmetallic mineral product manufacturing
Primary metal manufacturing
Fabricated metal product
Machinery manufacturing
Computer and electronic product manufacturing
Electrical equipment and appliance mfg.
Transportation equipment manufacturing
Furniture and related product manufacturing
Miscellaneous manufacturing

WHOLESALE TRADE
Merchant wholesalers, durable goods
Merchant wholesalers, nondurable goods
Electronic markets and agents and Brokers

RETAIL TRADE
Motor vehicle and parts dealers
Furniture and home furnishings stores
Electronics and appliance stores
Building material and garden supply stores
Food and beverage stores
Health and personal care stores
Gasoline stations
Clothing and clothing accessories stores
Sports, hobby, music instrument, book stores
General merchandise stores
Miscellaneous store retailers
Nonstore retailers

TRANSPORTATION AND WAREHOUSING
Air transportation
Rail transportation
Water transportation
Truck transportation
Transit and ground passenger transportation
Pipeline transportation
Scenic and sightseeing transportation
Support activities for transportation
Postal service
Couriers and messengers
Warehousing and storage

INFORMATION
Publishing industries, except Internet
Motion picture and sound recording industries
Broadcasting, except Internet
Telecommunications
Data processing, hosting and related services
Other information services

FINANCE AND INSURANCE
Monetary authorities-central bank
Credit intermediation and related activities
Securities, commodity contracts, investments
Insurance carriers and related activities
Funds, trusts, and other financial vehicles

REAL ESTATE AND RENTAL AND LEASING
Real estate
Rental and leasing services
Lessors of nonfinancial intangible Assets

PROFESSIONAL AND TECHNICAL SERVICES
Professional and technical services

MANAGEMENT OF COMPANIES AND ENTERPRISES
Management of companies and enterprises

ADMINISTRATIVE AND WASTE SERVICES
Administrative and support services
Waste management and Remediation services

EDUCATIONAL SERVICES
Educational services

HEALTH CARE AND SOCIAL ASSISTANCE
Ambulatory health care services
Hospitals
Nursing and residential care facilities
Social assistance

ARTS, ENTERTAINMENT, AND RECREATION
Performing arts and spectator sports
Museums, historical sites, zoos, and parks
Amusements, gambling, and Recreation

ACCOMMODATION AND FOOD SERVICES
Accommodation
Food services and drinking places

OTHER SERVICES, EXCEPT PUBLIC ADMINISTRATION
Repair and maintenance
Personal and laundry services
Membership associations and org.
Private households

PUBLIC ADMINISTRATION
Executive, legislative and general government
Justice, public order, and safety activities
Administration of human resource programs
Administration of environmental programs
Community and housing program administration
Administration of economic programs
Space research and technology
National security and international affairs