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A framework to find applications for organic molecules

A master thesis report

TU Delft

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A master thesis report

By

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Executive summary

Innovation is an important determinant for success in a fast changing world. For innovation to take place, scientific knowledge that has a proven working principle needs to find an application. The process in which applications are generated or identified has been identified as an important aspect of the innovation process. However, scientific literature on application generation or identification is underdeveloped.

The aim of this thesis was to develop a framework to generate or identify applications for organic molecules in a systematic way. This has been formulated into a research question as "Can a framework be developed to systematically search for applications for organic molecules?". Before this framework for organic molecules was developed, first a general framework to generate or identify applications for technology was created.

Apart from the main research question, three sub research questions are answered in this research:

Can a framework to systematically search for applications for technology be developed?

How can such a framework be translated to a framework for organic molecules?

How can this/these framework(s) be validated?

The framework was created using a design approach. The thesis draws on interviews with experts, scientific literature on application generation/identification frameworks and a discussion with experts.

In the preliminary literature study, the notion that the literature on the subject of application generation or identification is underdeveloped was confirmed. The available literature provided insufficient base to build this thesis, so a design approach was taken as alternative. The first step in this approach was a series of interviews with experts on innovation and application generation/identification. With the data from these interviews, a first version of the general framework was created. This first version was validated and improved by comparing it to frameworks from literature, by conducting a second series of interviews and by a discussion with experts.

The next step envisioned in the research was a translation of the general framework into a framework that can be used to generate or identify applications for organic molecules. A start was made on the translation of the framework by providing methods that can be used in subsequent research to translate the framework. The translation chapter used information from the second series of interviews as a starting point.

Following this research, four recommendations were made for future research project. The first recommendation is to further develop the framework created in this research project, for example by exploring creativity methods. Secondly, it is recommended to conduct a full systematic literature review, using the vocabulary learned throughout this thesis. Thirdly, the framework created in this thesis should be translated. Before translation can take place, it has to be researched what the best method for this translation is. The translation methods provided in this thesis could be used. Alternatively, new methods for translation could be devised and implemented. Finally, in future research, several concept used in this research should be defined more carefully. Obtaining more clear and workable definitions for these concept will decrease the ambiguity of future research using these concepts.

In conclusion, in this thesis, a framework to systematically generate or identify applications for technology (or rather, a concept in between scientific knowledge and technology) has been developed. Recommendations have been provided on how this framework could be further improved. On top of that, this research proposes methods for translation of this framework into a framework to systematically generate or identify applications for organic molecules. The actual translation has to take place in subsequent research.

Acknowledgements

I could not have written this thesis with the help of the people around me.

First and foremost, I would like to thank my supervisor, dr. J.R. (Roland) Ortt. During one of our first meetings, when the subject of my thesis was becoming clear, he told me I was going to have a hard time with the “empty sheet” nature of my project. On top of that, he told me that if (when) I made it through, I would learn a lot from the experience. I know now both his statements were true.
I feel that my supervisor found the right balance between guidance when I was lost and challenging me to think for myself when I only thought I was lost. Instead of pursuing his own scientific interests, I feel like he really was a supervisor for me and my scientific interests.

Next, I would like to thank the other two members of my committee, dr. H.G. (Haiko) van der Voort and prof. dr. ir. A.B. (André) de Haan. They both have invested considerable time in this thesis by reading it and providing in depth feedback.

Thirdly and lastly, I would like to thank all the respondents of the preliminary interviews, the second series of interviews and the discussion participants. Without you all, this thesis would not have been possible. Your input was very valuable and highly appreciated.

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1 Introduction

In this chapter, I would like to provide the reader with an introduction to this research. The aim of the research is provided, the research is placed in a larger (societal) picture and the main research question (RQ) is provided.
Next, the envisioned output is provided, both textually and graphically (figure 1). On top of that, the sub research questions (SRQs) are provided in this section.
After the envisioned output, the proposed methods for this research are provided. More on these methods is provided in the next chapter.
Lastly, the reader will be provided a brief outline of this thesis.

1.1 Aim of the thesis

The importance of innovation has already been recognized in 1942 by Schumpeter [50]. Since than, many authors have recognized its importance [51-53]. As stated by Koc and Ceylan [54], ideas are the main resource and starting point of innovation. In their paper, idea generation is identified as important determinant of innovative capacity (in large-scale firms). These findings are supported by other authors, for example Herstatt and Letll [40], or Linton and Walsh [55]. Strøm [1] concluded from a literature study that "application identification in a technology push context is theoretically underdeveloped, fragmented and in its embryonic stage". In this thesis, the idea generation in innovation is treated. A generic framework will be developed to systematically generate or identify applications for technology. Subsequently, this framework will be specified and expanded to accommodate the generation or identification of applications for organic molecules.

According to Koen *et al.* [56], the process going from an idea or concept to an application or a product is an inherently fuzzy process. In this thesis, I aim to create some systematicity in this fuzzy process, for the area of organic molecules. Or in more precise words:

> *In this research, a framework to systematically search for applications of organic molecules is developed.*

The choice for organic molecules is historically motivated: the master thesis in pursuit of my first master's degree was on the synthesis of a specific organic molecule.

N.B. both application identification and application generation are mentioned in the previous paragraph. The two are different, but often used interchangeably. They are treated as different throughout this thesis: application identification is a search and find process, applications that already exist are identified. On the other hand, application generation is a creative process, in which applications that do not yet exist (or that the generator is unaware of) are generated.

In the goal of this research, there are the words "framework", "systematic", "technology" and "application". I will explain these words and explain their specific relevance in my research goal before I continue to the envisioned output of this research.
To provide a definition for "framework", a slight modification to the term has to be made. A *conceptual* framework in research methods is defined by Shields and Rangarajan as "the way ideas are organized to achieve a research project's purpose" [57].
We borrow from this definition, changing it into a way in which concepts are organized to achieve a certain goal. Or specifically in this research, an organization of methods that facilitates the application generation or identification for technology.

For the definition of “systematic”, we turn to Jesson *et al.* [58], who defines systematic as “to work systematically simply means to work in an ordered or methodical way, rather than in a haphazard or random way”. Combining this definition with the previous definition (the definition of a framework), one might say a framework is inherently systematic. However, the “systematic” also relates to the methods in the framework.

Thirdly, a definition for technology. Searching for a scientific definition, someone quickly stumbles upon papers that take an etymological and philosophical approach.
In an attempt to define technology, Agar [59] starts from an instrumentalist definition that is “technology are means to ends”. He adds material, designed and intervention between scales, but does not summarize these into a new definition of technology. An attempt at integration would yield a definition for technology that is: “technology is a designed, material means to and end that is capable of intervening between scales” (an example of intervention between scales can be found in cars, where a the small movement of hand on a stirring wheel is translated into a larger movement of turn on the road).
In a paper from computer fraud & security journal [60] (please note, the paper does not mention an author, so the name of the journal’s editor has been provided), a similar approach is taken, but they too remain vague about the actual definition of technology. The most boiled down definition provided in the paper comes from A.S. Paau, director of technology transfer at the university of California, who poses “technology is knowledge to do something”.
Combining these two definitions, technology is knowledge that is or could be used to accomplish something (“an end”). This might yield a paradox, in the sense that the general framework developed in this research aims to find applications for technology, while technology is only technology if it has practical usability. On top of that, the definition is still very general. Both issues are discussed in the discussion chapter of this research.

Lastly, and maybe most importantly, a definition for application or even “application of technology”. In a paper by Gardner [61], the superficial treatment of the term “application” is discussed. The paper does not offer a definition, but does offer some boundary conditions: application is about moving scientific knowledge from invention, through prototype to a (commercial) product. The paper offers that application involves translation and reshaping of knowledge: “Before a technologist can make use of a scientific idea, that idea must often be translated into a more useable form.”
In an attempt to find more sources for a definition, we turn to Cambridge online dictionary, which defines application as “a way in which something can be used for a particular purpose” [62].
From these definitions, I combine the notions of “knowledge”, “usability” and “purpose” to yield: “application is the use of scientific knowledge embedded in a product or service for a particular purpose.”

1.2 Envisioned output

As stated above, the envisioned output for this research is a framework. This framework is presented graphically as a flowchart (an impression of this presentation is provided in figure 2). As initial idea, a four-phase framework is proposed, with an information gathering phase, an application generation or application identification phase, an application selection phase and an application development phase. These four phases are obtained from the knowledge base from my supervisor and myself respectively. My supervisor obtained this knowledge base through years of research on innovation processes, my research base has been obtained during this thesis, through reading (relevant) literature. The four phases are used as a starting point for an iterative framework development process. The phases will be altered, extended and improved with the data gathered during this research project.

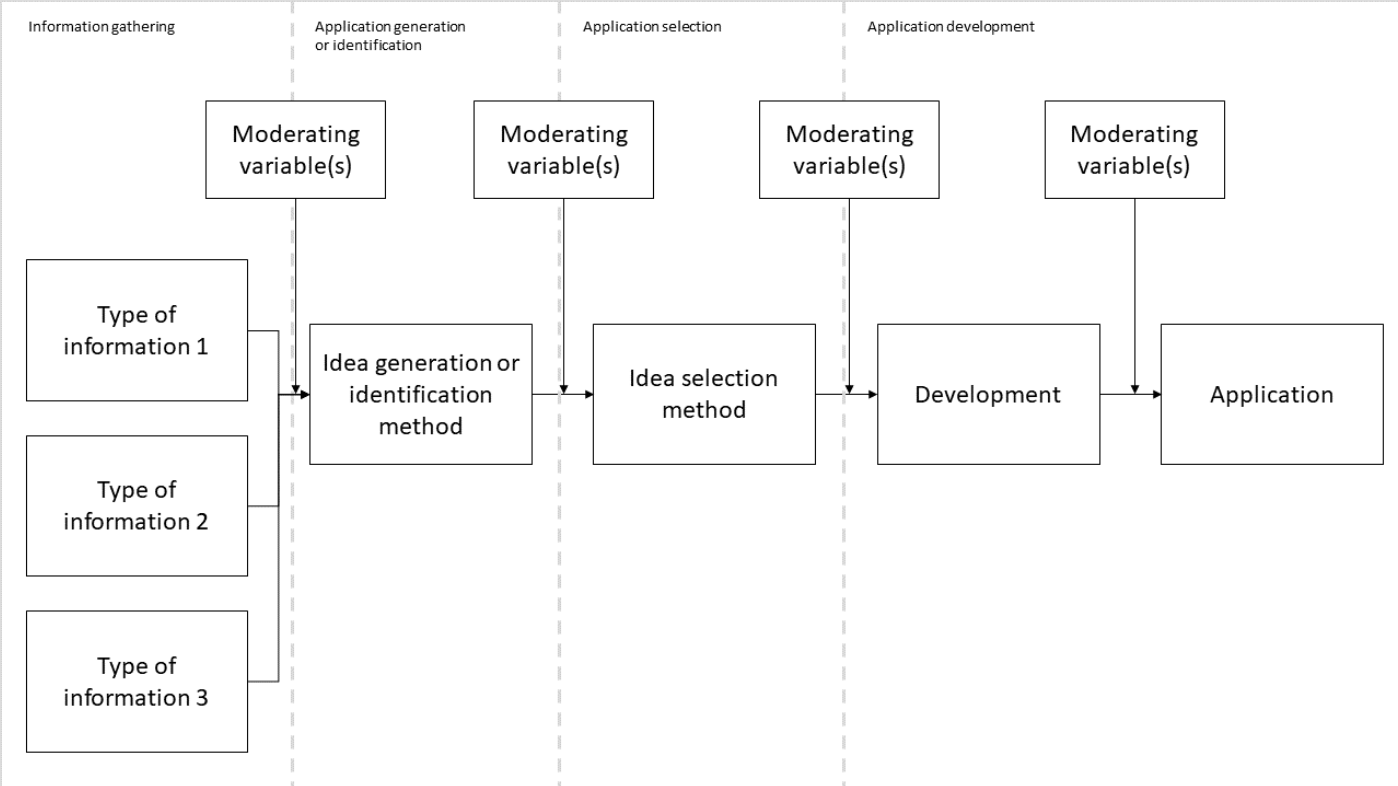

Figure 1: Graphical representation of the envisioned output.

In this research, the main RQ is "Can a framework be developed to systematically search for applications for organic molecules?"
Several SRQs arise for the main RQ:

1. Can a framework to systematically search for applications for technology be developed?
2. How can such a framework be translated to a framework for organic molecules?
3. How can this/these framework(s) be validated?

1.3 Proposed methods

In figure 2, the proposed methods for this thesis are presented. They can be divided into four phases: a generation phase, a validation phase, a translation phase and an application phase.
First a generic framework will be developed (generated) to systematically identify or generate applications for technology. Subsequently, this framework will be validated (and improved). Next, the framework will be specified and expanded to accommodate the identification or generation of applications for organic molecules. Lastly, the framework will be applied to generate or identify applications for the molecule from my first master thesis.

Two methods will be used in the generation phase of the research, a literature study and a set of (preliminary) interviews. During these first two steps, a collection of methods to generate or identify applications for technology will be obtained. With these methods, a first version of the general framework will be synthesized.

After the first version of the general framework has been created, it will be validated using three methods: a second series of interviews, comparison to (frameworks from) literature and a discussion with experts.
In the second series of interview, experts from the preliminary interviews that have a background in chemistry will be interviewed again. The candidates will be asked to provide feedback on the general framework and suggest ways to translate the framework towards organic molecules.

The comparison of the created framework to literature is literally that: frameworks for the generation or identification of applications for technology will be identified in literature. The characteristics of these frameworks from literature will be compared to the framework created in this thesis.
The expert discussion will be held with another selection of experts from the preliminary interviews. The discussion will focus on validating/improving the general framework.

When the framework has been validated it will be translated towards organic molecules. From the second series of interviews, a first collection of translation methods will be obtained. Depending on the elaborateness or the perceived completeness of this list, literature on how to perform this translation will be reviewed. With the (expanded) list of translation methods, the framework will be translated.

Finally, to show the workings of the translated framework, the framework will be used to identify applications for the molecule of my first master thesis.
For a more detailed description of the methods used in this research project, please refer to chapter 2.

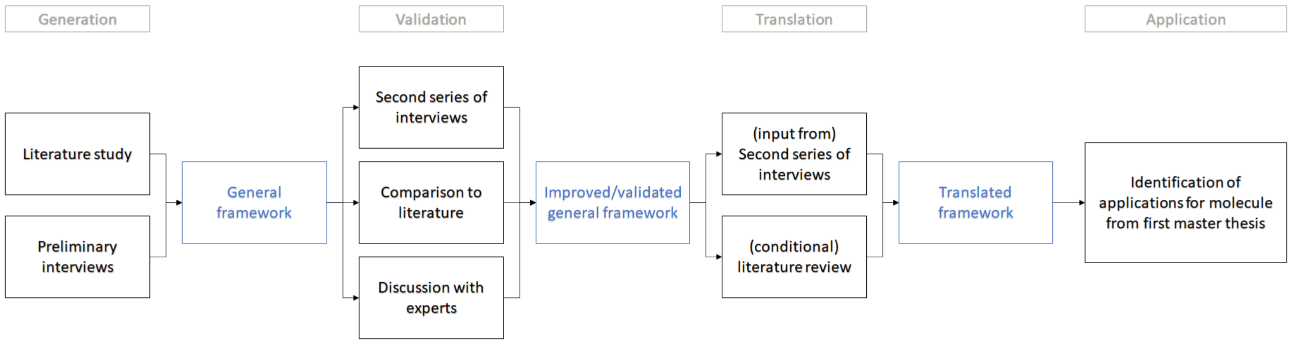

Figure 2: Proposed methods for the creation of the general and specified frameworks.

1.4 Thesis outline

The structure of this thesis is closely related to the structure provided in figure 2. Where this thesis deviates from the proposed structure of figure 2, an updated version of the figure will be provided.
In this first chapter, this thesis was introduced, providing the aim of the thesis, the envisioned output and a first glance at the methods that are used in this thesis.
The second chapter is the first chapter on the generation phase. In this chapter, the first literature study is presented. The methods and keywords used in the literature study are provided and the findings (or the lack thereof) are presented. In the concluding section of this chapter, a new approach to this thesis is provided.
In the third chapter, further research design is discussed. The methods from all four phases described in figure 2 will be discussed, excluding the literature, since it was already provided in chapter 2.
The fourth chapter is the second and last chapter on the generation phase. The results of the preliminary interviews are presented and discussed. A first version of the general framework is created.
In the fifth chapter, the results of the second literature study are presented, providing information needed in the sixth chapter on the validation phase of this research.
In the sixth chapter, the framework validation will be considered. In this chapter, all three proposed methods of the validation phase seen in figure 2 are discussed. First the general framework from chapter four is compared to the frameworks that have been identified in literature. Next, the results of the second interview series and the expert discussion are discussed.
In chapter seven, the translation of the framework is considered.
In chapter eight, a general conclusion, a discussion and suggestions for future research are provided.

2 First literature study

In a first attempt to find methods (or frameworks) for the (systematic) generation or identification of applications for technology, the following inquiries were done in Google scholar:

> TITLE-ABS-KEY (methods for finding applications for innovations)
> TITLE-ABS-KEY(how disruptive technologies find their applications)
> TITLE-ABS-KEY(technology push innovation search application)
> TITLE-ABS-KEY(allintitle: technology search application)
> TITLE-ABS-KEY(allintitle: technology need application)
> TITLE-ABS-KEY(allintitle: technology push application)
> *Please note, the "TITLE-ABS-KEY" can not be used as command in Google scholar, but the search engine searches in title, abstract and keywords by default.

From these search terms, several articles have been identified that looked promising based on their title and/or abstract. Furthermore, through forward and backward snowballing, additional aritcles were identified. An overview of the identified articles and the reasoning from one article to the next can be found in appendix A.
Although several articles were reviewed that looked promising, no collection of methods to generate or identify applications for technology was obtained through this first literature study. It is believed this is caused by two main reasons:
The first reason has to do with the overall development of the scientific field of application generation or identification. As indicated before, it was concluded by Strøm [1] that "application identification in a technology push context is theoretically underdeveloped, fragmented and in its embryonic stage". This conclusion is confirmed by the first literature study of this thesis. No articles were found that talk about the specific subject of generating or identifying applications for technology.
The second reason hast to do with my own frame of reference. Since the field of application generation or identification is new to me, it was difficult to appreciate the pieces of knowledge provided in the articles mentioned in appendix A. Without a scaffold or larger picture in which knowledge can be placed, it is difficult to identify useful knowledge.

To build the scaffold that was just discussed and to overcome the lack of useful knowledge obtained from the first literature study, a design approach was taken in this research. In stead of building a first version of the framework on information obtained from literature, this first version was designed using the input from the preliminary interviews. This approach has been summarized in figure 3, an updated version of figure 2. After the interviews were conducted and a scaffold had been created, the literature was consulted again. The relevant frameworks found in this (second) literature study are described in chapter 5.

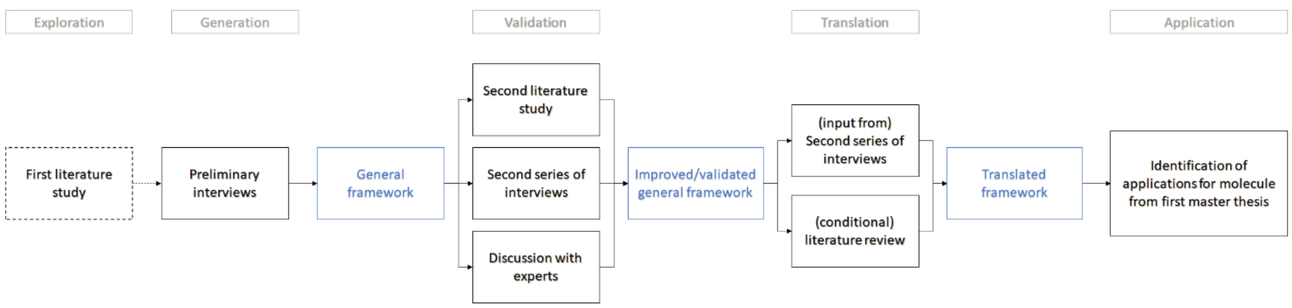

Figure 3: Updated methods for the creation of the general and specified frameworks.

3 Research design and methods

This chapter builds upon section 1.3 by further exploring the methods that were used during this research project.
As was just discussed, after an unsatisfactory result was obtained from the first literature study, a design approach was taken in this thesis. The proposed methods are provided in figure 3 and will be further discussed in this chapter. First the preliminary interviews are discussed (N.B. this section is not named “generation”, but rather “preliminary interviews”, since preliminary interviews are the only method used in this phase). The validation phase is discussed next, considering the second literature study, the second interview series and the expert discussion. Thirdly, the framework translation is discussed, revisiting the second interview series and elaborating on the conditional literature review. Lastly, the proposed framework application is discussed.

3.1 Preliminary interviews

As mentioned before, the first step in this research are the preliminary interviews. The aim of the interviews is to obtain the experts’ methods to generate or identify applications for a technology. The methods of each interviewee will be summarized in rough frameworks created with the interviewee during each interview. With these frameworks, a first version of the framework to generate or identify applications for technology will be created.
Two types of candidates will be consulted: scientists and experts from industry. The interviews will be semi-structured, to obtain a balance between guidance for the candidates during the interview, but not trapping the candidates in a rigidly structured interview.
Candidates will be asked to participate in the interview via email. After the interview, candidates will receive another email, thanking them for the interview and providing them a summary of the interview. The emails can be found in appendix B (B.1 till B.4).
Due to the corona crisis, most interviews were held over digital communication media.

3.1.1 Interview questions

As stated before, the aim of the interviews is to obtain the experts’ methods to generate or identify applications for a technology. To accomplish this, the following questions are prepared for the interviews:

- Do you have any experience with finding applications for technologies?
- If not, do you have any secondhand experience?
- How would you go about finding applications for something new?

- How would you go about comparing these methods? Which criteria would you use?
- Do you know any literature to substantiate the methods you just mentioned?

- Do you see any form of grouping in the methods we have so far?
- How would you go about organizing the different methods into these groups?
- Do you see any way to combine different methods and/or groups? If so, how?

- Would you like to add anything to what you have said so far?
- May I approach you again in a later stage of the research? (to test the framework)

3.1.2 Candidates

In appendix C an overview of all interview candidates can be found. For each candidate, a short biography has been provided. The candidates that will be interviewed during the preliminary interviews are candidate 1 through 14.

3.2 Framework validation

With the results of the preliminary interviews, a first version of the framework to generate or identify applications for technology will be created. After creation, this framework will be validated through three methods: a second literature study, a second interview series and an expert discussion.

3.2.1 Second literature study

A first step in the framework validation will be a second literature review. Using the knowledge from the preliminary interviews as scaffold and to generate keywords, it is believed a literature study at this point will have more success than the first literature study.
The aim of the second literature study is to identify frameworks that treat the process of generating or identifying applications for technology, so these frameworks can be compared to the framework created with the results of the preliminary interviews. In chapter five these frameworks will be presented and in chapter six, these frameworks will be compared to the framework created with the input from the preliminary interviews.

3.2.2 Second interview series

After the second literature study, a second interview series will be held. In these interviews, candidates will be asked to provide feedback on the created framework. On top of that, they will be asked to provide methods for the translation of the framework into a framework specified towards organic molecules.
The interviews will again be semi-structured. Candidates will be asked to participate in the interview via email. After the interview, candidates will receive another email, thanking them for the interview and providing them a summary of the interview. The emails can be found in appendix B (B.5 and B.6).

3.2.2.1 Interview questions

Every candidate from the second series of interviews will be provided with a graphical representation of the most recent version of framework developed in this research. After each interview, the results will be used to improve the framework. This means every candidate will get different input for the interview. This way, each interviewee will be able to build upon the results of the previous interviewee.
During the second interview, two questions will be asked:

- How do you think the proposed framework can be improved? (used in validation)
- How do you propose the translation towards organic molecules can be made? (used in translation)

3.2.2.2 Candidate selection

The candidates for the second interview series will be a selected subset of the candidates selected for the preliminary interviews. By selecting candidates that have a background in chemistry, the dual purpose of the second interview series (validation and translation) can be achieved. The candidates interviewed in the second interview series are the candidates 7, 9, 11, 12 and 13.

3.2.3 Expert discussion

The third and final step in the framework validation is an expert discussion. The candidates will be presented with the general framework and asked what their thoughts on the framework are, how they think the identified phases should be ordered (sequential, iterative, random, etc.) and what the role of lead-users, the market and industry is.
The candidates will be selected such that the resulting group is as diverse as possible in terms of background, expertise and experience. The diversity is chosen as parameter to facilitate a better discussion environment and to tap into the added value a diverse group can create [63] in the framework development. N.B. the candidates that will be interviewed a second time will not be included in the discussion, since they already provided their input.

The discussion candidates are:

- Candidate 4
- Candidate 10
- Candidate 14

Looking at appendix C, it can be seen that the provided group is indeed diverse: candidate 4 is a professor at industrial design that has experience as a management consultant and a research interest in innovation, while candidate 14 has a background in business administration and experience in technology transfer from university to industry, and candidate 10 has a background in mechanical engineering and is currently working on smart materials.

3.3 Framework translation

After a framework is created and validated, the framework will be translated. In this step, the framework will evolve from a framework to generate or identify applications for technology to a framework to generate or identify applications for organic molecules.
The input from the second series of interviews concerning the translation of the framework will be used as a starting point for the framework translation. For the translation step, another candidate will be interviewed in the second interview series: the supervisor of my first thesis (candidate 16). He has several years of experience in organic chemistry, so his knowledge is useful in the translation of the framework.
A literature review might be used in the framework translation, to expand the information that will be provided by the candidates from the second interview series and/or to find translation methods that have not been mentioned during the interviews. If the input from the second interview series is perceived as sufficient for the framework translation, the literature review in this phase will be skipped.

3.4 Framework application

The last step in the framework development will be the application of the framework to the molecule of my first master thesis. The molecule will be used as a test case to see whether the developed framework works. Based on the outcome of this test case, further development recommendations will be provided towards the end of this thesis.

3.5 Concluding

In this chapter, the methods that will be used in the development of the framework have been provided. Future changes to the collection of proposed methods will be provided in the form of an updated version of figure 3.
In the next chapter the result of the preliminary interviews and a first version of the framework will presented.

4 Results preliminary interviews

In this chapter, the results of the preliminary interviews are discussed. For every interview that was done, an interpretation of the interview is available in appendix D. On top of that, during most of the interviews, frameworks were created together with the interviewee. These frameworks can be found in appendix E. All elements that from the preliminary interviews that could be relevant but have not been presented in this chapter can be found in appendix F.

In the first section of this chapter, I would like to provide some definitions that are important in the analysis of the interview results.
In this second section, the results of the interviews are analyzed and compared. This analysis is based on the four phased framework concept provided in section 1.2. An overview of the phases and the fit of the different interviews into these phases is provided by Table 1. On top of that, new phases are proposed to improve the framework and interviews without a framework are discussed.
The chapter concludes with a section on how the information in this chapter will be used throughout the rest of this thesis.

4.1 Definitions

Some terms that are used in the description of the results in this chapter require a precise definition, to be able to keep track of the proposed logic in the results. In principle, the definitions were obtained from the online version of the Cambridge English dictionary [62] and were supplemented where this was deemed appropriate to better suit this research project:
Prototyping: "the activity of making basic models or designs for a machine or other industrial product". In this research, where a framework is developed to find applications for organic molecules, prototyping is a demonstration of a molecule in its envisioned application. An important boundary is (potential) user involvement: in prototyping, in principal no (potential) users are involved.
MVP testing: MVP, or minimum viable product testing, is not a single word, thus no definition exists in the Cambridge online dictionary. However, Moogk [64] provides a definition: "a version of the product that is complete enough to demonstrate the value it bring brings to the users". As opposed to prototyping, (potential) user involvement is key.
Trial and error: surprisingly, Cambridge dictionary does offer a definition for trial and error: "a way of achieving an aim or solving a problem by trying a number of different methods and learning from the mistakes that you make". This is translated into this research by linking the "trying a number of different methods" to the generation phase of a potential framework and the "learning from your mistakes" to the selection phase.
Experimentation: according to the Cambridge dictionary: "the process of trying methods, activities, etc. to discover what effect they have". Rather similar to the definition of trial and error, although no explicit attention is given to the "learning from one's mistakes". In this research, experimentation will be used as a method for both the generation phase and the selection phase of a potential framework. No important differences between trial and error and experimentation are recognized for the purpose of this research.
User: "someone who uses a product, machine or service"
Lead user: a concept defined by Von Hippel [65]. Lead users are people that have two characteristics: they face certain needs much earlier than the bulk of the marketplace and they are positioned to benefit significantly from a fulfillment of those needs.

4.2 Combined interview results

During the interviews, the questions as presented in section 3.2.2.1 turned out to be optimistic. These questions insinuate that an interviewee provides a list of methods that can be compared, grouped and combined. However, often the interviewees provided one or a few methods to find applications for a technology. This means the questions on how to compare, group and combine the methods were often not asked. Instead it was found to be easier to work with the interviewee to create a basis for a framework during the interview. After the interview, the frameworks were expanded with information from the interviews and sent to the interviewees for approval. As stated before, these frameworks can be found in appendix E.

4.2.1 Initial four phases

To analyze the interview results, the fit between the frameworks from the interviews and the phases identified in section 1.2 was assessed. The four phases are: an information gathering phase (IGP), a application generation or identification phase (AGP), an application selection phase (ASP) and an application development phase (ADP). In table 1 you will find an overview of which interview fits the initial four phases (and which of the four phases). Below the table you can find a discussion on each of the initial four phases. Lastly, for each separate phase, a table is provided, summarizing the most important topics discussed during the interviews with respect to the specific phase.

	Code	IGP	AGP	ASP	ADP
Candidate 1	I-010	X	X	X	X
Candidate 2	I-020	X	X	X	X
Candidate 3	I-030	X	X	X	X
Candidate 4	I-040	X	X	X	
Candidate 5 (1)	I-050	X			
Candidate 5 (2)	I-051	X	X	X	
Candidate 6	I-060	X		X	
Candidate 7	I-070	X	X	X	
Candidate 8	I-080	X			
Candidate 9	I-090	X	X	X	X
Candidate 10	I-100	X		X	X
Candidate 11	I-110	X	X	X	X
Candidate 12	I-120	X	X	X	

Table 1: A comparison of the frameworks created during the preliminary interviews.

4.2.1.1 Information gathering phase

As was mentioned before, each section that describes a phase will have a table that summarizes the most important results of the interviews with respect to that phase. For the information gathering phase, please refer to table 2.

As can be seen from table 1, all frameworks that have been obtained through the preliminary interviews include some form of information gathering phase. Both a classification of information and methods to gather information have been mentioned in the interviews. The information has been summarized in figure 4 and an overview of which information has been provided by which interview has been presented in table 3.

Some frameworks have already been specified towards molecules at this point, due to a combination of the background of the interviewee and a framing in the questions that were asked. An example of such framework is I-110, where properties of the molecule are determined after the structure has been determined. This makes sense, since there is often a (clear) relation between structure and properties (for example, via quantitative structure property relationships, or QSPRs [66, 67]).

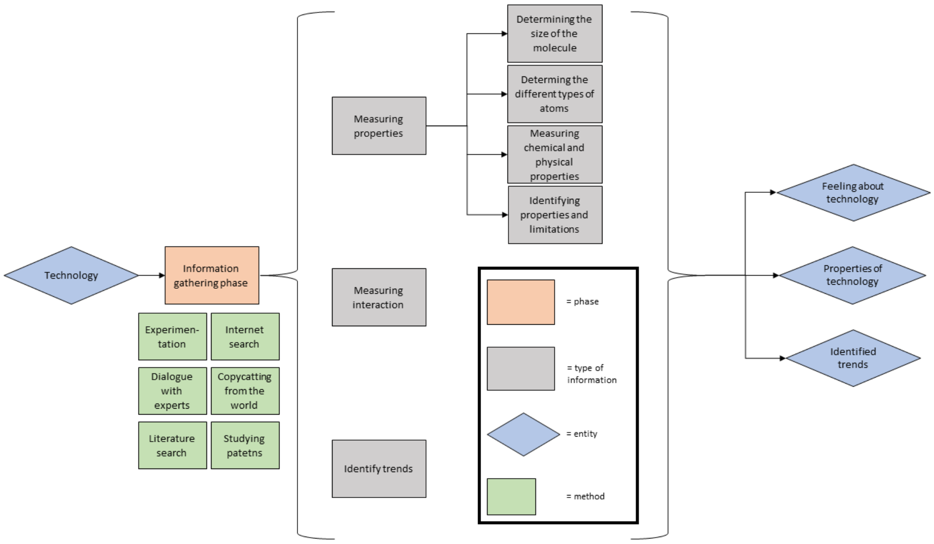

Figure 4: The information gathering phase.

What is missing from most frameworks is a description of which properties should be measured. This is something that has to be determined to make the final framework practically applicable.

Overall, the information gathering in the frameworks that have been discussed so far can be summarized as measuring (physical and chemical) properties and determining the (molecular) structure.

Several methods to measure properties have been provided, but there is no real consensus on which methods should be used. Based on most mention, experimentation, dialogue with experts, literature search and studying patents are the best methods.

Interviewee	**Remark**
Candidate 2	Interaction with the [technology] (material) is important.
Candidate 3	Technology maturity is important, at what level of maturity do you start looking for applications?
Candidate 5	Talk to experts on the technology, since they know where the benefits of their technologies lie with respect to other technologies.
Candidate 8	Start with a patent, since a patent describes exactly what a technology can do.
Candidate 8	To describe what a technology can do, fill in the sentence “we know how to …”.
Candidate 10	Apart from the technical characterization, you might have an experiential characterization.
Candidate 11	You need to think about the relation between properties and structure.
Candidate 11	It is difficult to determine what properties to measure. Probably, an expert on a technology only measures what he perceives as important through his/her area of expertise.
Candidate 13	Start with functionality.

Table 2: Important statements from the preliminary interviews about the information gathering phase.

Code	Measuring properties	Chemical and physical properties	Identifying properties and limitations	Measuring interaction	Identify trends	Experimen-tation	Dialogue with experts	Literature search	Internet search	Copycatting from the world	Studying patents
I-010	X				X					X	
I-020	X			X							
I-030	X				X						
I-040	X										
I-050							X				
I-051							X				
I-060	X										
I-070	X					X		X			X
I-080											
I-090	X										X
I-100		X									
I-110	X										
I-120			X	X		X	X	X	X		

Table 3: Overview of which information and which methods have been provided in which interview for the information gathering phase.

4.2.1.2 Application generation or identification phase

The most important results of the application generation or identification phase have been summarized in table 4. The application generation phase is something that has been identified as part of the process of finding applications for technologies or molecules by most interviewees. In some interviews where it has not been recognized, an alternative has been proposed in the from of an application matching phase. More on this in section 4.2.2. The information has been summarized in figure 5 and an overview of which information has been provided by which interview has been presented in table 5.

Interviewee	Remark
Candidate 1	It is important to have a certain experience in the area of application, to know what is possible and what is not.
Candidate 1	[Creativity] should not involve any selection.
Candidate 2	I would try to turn disadvantages into advantages and do this phase with a group.
Candidate 3	Before you involve other people in your creative process, it might be good to consult your own creativity.
Candidate 3	Finding applications is about bringing people, problems and solutions together.
Candidate 4	In my experience as a management consultant, applications were always found through creativity techniques.
Candidate 8	Diversity in the group of people that is doing creativity is very important.
Candidate 8	You need people that have been trained in creativity.
Candidate 9	With creativity, there is a certain amount of intuition needed.
Candidate 11	A blunt way to find application could be high-throughput experimentation.
Candidate 12	Showing properties of a technology in a way that they are not shown often might facilitate creativity.
Candidate 12	You need a group of people with experience in different areas of expertise.
Candidate 14	Finding applications is not the exciting part, the exciting part is how to implement the applications in the real world.

Table 4: Important statements from the preliminary interviews about the application generation or identification phase.

As can be seen from table 5, most interviewees agree that the application generation or identification phase should involve idea generation. The identified methods are creativity or dialogue with experts. Some interviewees propose a combination of the two methods.

Creativity is not a trivial matter, evident by the fact that entire books have been written about creativity techniques and how to use them (for example, the book by Tassoul [68]). Creativity might seem an unsystematic part of an otherwise systematic framework. However, briefly considering the book by Tassoul as an example, elaborate methods and techniques exist to perform creativity. The outcome of these methods will always be somewhat serendipitous in nature, but the methods themselves are systematic in their setup. In subsequent research, a more in-depth review of relevant creativity methods is needed to improve this phase of the framework.

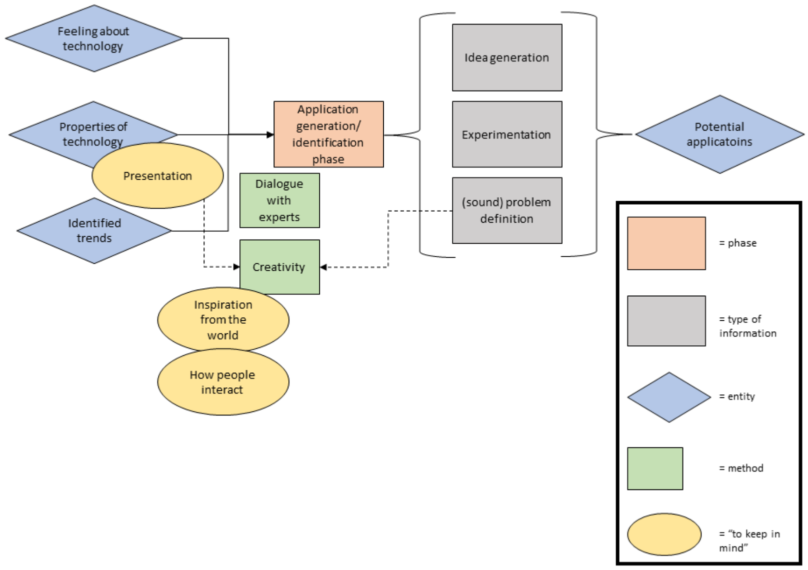

Figure 5: The application generation or identification phase.

The current phase is called "application generation and identification phase". The idea that applications can be identified instead of generated has been hinted at during the interviews, for example by the mention of patents as information sources. However, the identification phase has not been equally represented in the interviews compared to application generation. This might be due to framing or bias from my side towards the interviews, but this is just speculation. Application identification will return during the literature review.

Code	**Idea generation**	**Experimen-tation**	**Sound problem definition**	**Dialogue with experts**	**Creativity**
I-010	X				X
I-020	X				X
I-030	X		X		X
I-040	X				X
I-050				X	
I-051	X			X	
I-060					
I-070	X	X		X	X
I-080					
I-090	X			X	X
I-100					
I-110	X			X	X
I-120	X				X

Table 5: Overview of which information and which methods have been provided in which interview for the application generation or identification phase.

4.2.1.3 Application selection phase

The most important results of the application selection phase have been summarized in table 6.

Interviewee	Remark
Candidate 8	During selection, you can contact the inventor/expert and ask whether the possible applications found in the creative session are possible.
Candidate 13	Other ways to rank the possible applications you have found are the ability to execute that a company has, the freedom to operate, access to funding and required competences and/or partners.
Candidate 13	Think about how to get everyone involved in the process to agree on an application.

Table 6: Important statements from the preliminary interviews about the application selection phase.

The application selection phase is something that has been identified as part of the process of finding applications for technologies by most interviewees. The information has been summarized in figure 6 and an overview of which information has been provided by which interview has been presented in table 7. Not all frameworks that have a selection phase are featured in table 7, which could be an indication that elements from the application selection phase are missing from figure 6.

Some interviewees skip quickly over the selection process, without providing methods to perform the selection. Other interviewees mention selection criteria. Selection criteria can be based on the technology itself, for example the value proposition, or a comparison with old technologies in the same application.

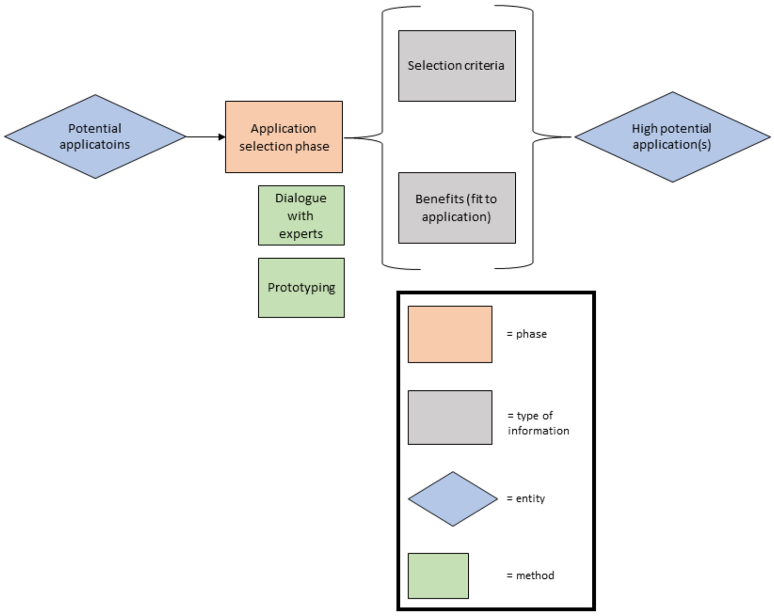

Figure 6: The application selection phase.

Code	Selection criteria	Benefits (fit to application)	Dialogue with experts	Prototyping
I-010	X		X	X*
I-020				X*
I-030				
I-040				
I-050		X		
I-051				
I-060				
I-070				X*
I-080				
I-090				
I-100	X			X*
I-110				X*
I-120				

*will be discussed in next section

Table 7: Overview of which information and which methods have been provided in which interview for the application development phase.

Thirdly, they can be based on the business environment around the technologies, for example freedom to operate, ability to execute, access to funding and needed competencies or relations.
Another method mentioned in this framework is trial and error. However, it is mentioned as happening before selection. Trial and error can be used as a generative and selective process at the same time, as was discussed in the definitions of section 4.1. It will be presented in the framework as "prototyping", since it is believed that in application selection, trial and error will always involve the creation and testing of a proof of concept (which is effectively prototyping).
A last method considered in the selection phase is "dialogue with experts". Experts on the technology can be consulted to learn the capabilities and limitations of a technology, so that the proposed applications that are not within these capabilities can be discarded.
Lastly, an interesting question to consider is whom to include in the selection process (for example, lead users). More on this in the next section.

4.2.1.4 Application development phase

Some of the frameworks created during the interviews include some form of development phase. The most important results of the application development phase have been summarized in table 8.

Interviewee	Remark
Candidate 8	When you have an initial application idea, you want to talk with people in that field of application and ask their opinion. Now you can improve your idea with every person you talk to.
Candidate 8	You might want to involve lead-users to develop a product from the application you identified.

Table 8: Important statements from the preliminary interviews about the application development phase.

In this phase, the application goes from a mere idea to an application (and thus a product or service, please refer to the definition of "application" in chapter 1). Two methods for idea development/improvement are mentioned, prototyping and MVP testing.
In line with the previous section, where prototyping was identified as both selection and development, prototyping is provided again in this phase.
An interesting question to consider in further framework development is whether to include lead users and/or potential customers into this phase. This will be addressed in section 6.1.2.1.
No table like table 7 has been created for this phase, since it is believed it will not add any information. However, a figure of the phase has been provided, see figure 7.

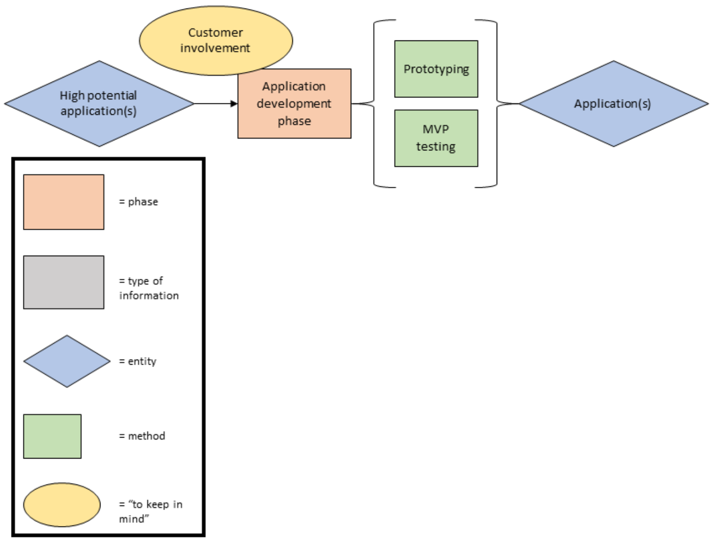

Figure 7: The application development phase

4.2.2 New phase 1: application matching

The most important results of the application matching phase have been summarized in table 9.

Interviewee	Remark
Candidate 11	If you could create a model where you put in the different classes of molecules with their possible applications, add the known structure/properties relationship and refine this model with test cases (molecules that already have their applications), you might end up with a model that is capable of finding applications for new molecules.

Table 9: Important statements from the preliminary interviews about the application matching phase.

Application matching could prove an interesting method to include in the framework as alternative to the application generation phase (either as alternative to creativity, or in combination with creativity). As alternative, the search for existing applications in a database can provide applications without creativity. As combination, application matching might be used to identify an area of application (as indicated in I-100) and provide direction for the subsequent creativity used to generate potential applications.

For example, the frameworks I-060, I-080 and I-100 start with an information gathering phase, as can be seen from table 1, after which they propose to identify certain categories to sort the technologies or molecules. Now these categories link to a premade database. In this database, the categories are linked to certain applications. By sorting the technology or molecule into the right category and feeding them into the database, the database will provide one or more possible applications for the technology or the molecule. N.B. in I-060 these "categories" are called "classes", but the principle stays the same. An interesting question to answer for this method is how to create the database needed in this application matching. Framework I-100 provides an interesting take in this database creation (or rather, evasion of it), by using the already existing database (either IP or the entire internet). Creativity can be used in combination with these search engines, by being creative with the search terms used in these search engines. Now to separate good and bad results from the search engines, domain knowledge is needed. However, once this is done, the user has a list of possible applications or application areas. The next step is selection, which is discussed above in section 4.2.1.3.

An overview of the discussed application matching phase has been provided in figure 8.

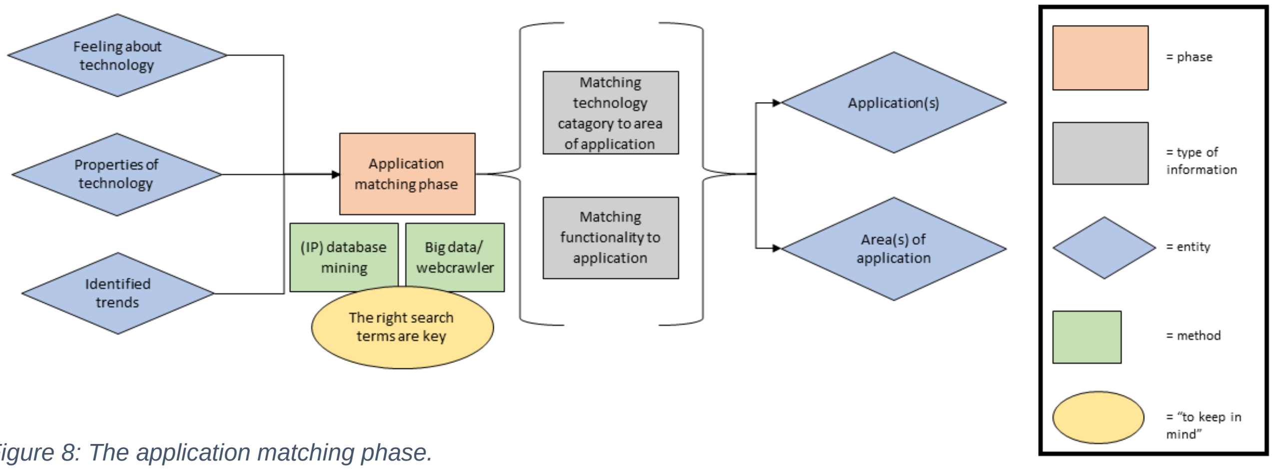

Figure 8: The application matching phase.

4.2.3 New phase 2: area of application identification

The most important results of the area of application identification phase have been summarized in table 10.

Interviewee	Remark
Candidate 4	Creativity needs direction, otherwise it is useless.

Table 10: Important statements from the preliminary interviews about the area of application identification phase.

It is believed the identification of an area of application will have a place in the final framework. How the area of application will be found still has to be determined. It is postulated that it will either be a creative process (as for example described in I-070) or a matching process as described in the previous section.

An overview of the area of application identification phase is provided in figure 9. Several of the interview frameworks identify an area of application somewhere in the process of finding an application. It is believed the identification of an area of application before the generation of applications might provide guidance in the creative process. This could both be beneficial (as the results of the generation processes might be more thorough within the area of application that was identified) and detrimental (since a more narrow focus early on in the generative processes might yield less results or results that are less "out of the box").

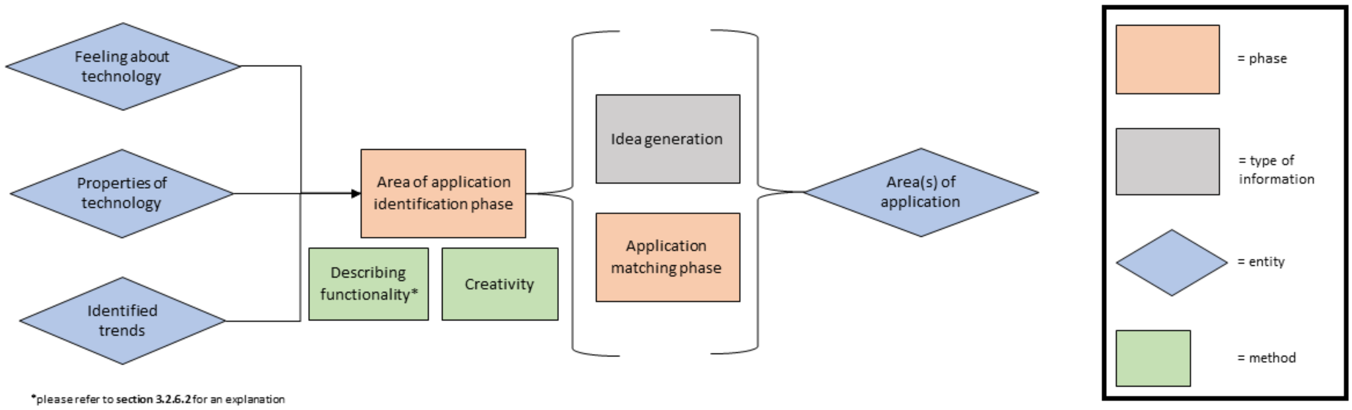

Figure 9: The area of application identification phase.

4.2.4 Interviews without framework

Two interviews, with candidate 6 and candidate 14 respectively, did not yield a framework. In this section, I will the relevant information from these interviews.

Candidate 6 mentioned some methods during the interview to search for applications. He mentioned the importance of creativity, contact with peers/experts and something that closely resembles the previously described matching system ("Another way…over time.", appendix D, D.6). When asked to rank the methods, he said the methods happen in sequence, in parallel and everything in between. He mentioned the importance of deciding what you want the dimensions of the output of the framework to be (for example, product vs material).

Candidate 14 talked about the importance of business development alongside the application development. According to him, finding applications is not the exciting part of the process, implementing the application in the real world is. To his experience, an application can only fully develop once it is developed into a product. (please note that this is not in line with the definition of application that has been provided in chapter 1). Which applications develop dependents on the obstacles faced during implementation.

When discussing the process used to find applications for a technology, he commented that already the different types of technology coming from the faculty of applied sciences are too broad to capture in a single framework.
A final comment made during the interview is to get a clear distinction between application and product.

4.3 Application in the rest of the research.

In this section, the results from this chapter are summarized in the form of an updated version of table 1 and two updated versions of the general framework created in this thesis.

	IGP	AAP	AGP/MAP	ASP	ADP
I-010	X		X	X	X
I-020	X		X	X	X
I-030	X	X	X	X	X
I-040	X	X	X	X	
I-050	X	X			
I-051	X		X	X	
I-060	X	X	X	X	
I-070	X	X	X	X	
I-080	X		X		
I-090	X		X	X	X
I-100	X		X	X	X
I-110	X		X	X	X
I-120	X	X	X/X	X	

Table 11: A comparison of the frameworks created during the preliminary interviews, including the newly identified phases.

As can be seen from table 11, the two newly introduced phases are featured in several frameworks. Although not as quantitative as it might seem, it is an indication that the new phases make sense in the framework.
Below in figure 11 you will find an overview of how all the different phases discussed in this chapter fit into a framework. For more detail on each respective phase, please refer to the section dedicated to that phase.

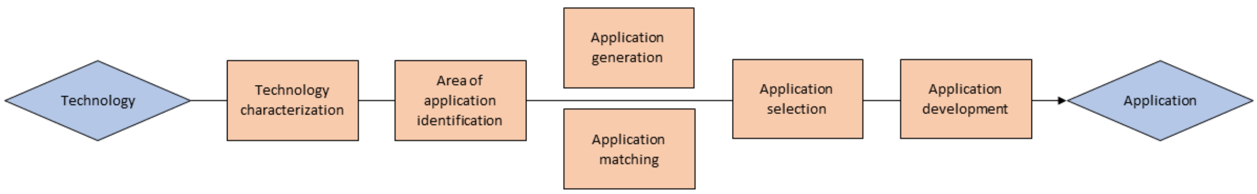

Figure 10: The developed framework, version 1.

Another concept for a framework has a selection phase both before and after the development phase, as depicted in figure 12. This idea originated from a reconsideration of the application development phase and a revisit of several frameworks: I-010, I-020, I-070 and I-100, several potential applications go into the prototyping (or experimenting) phase and one applications comes out.

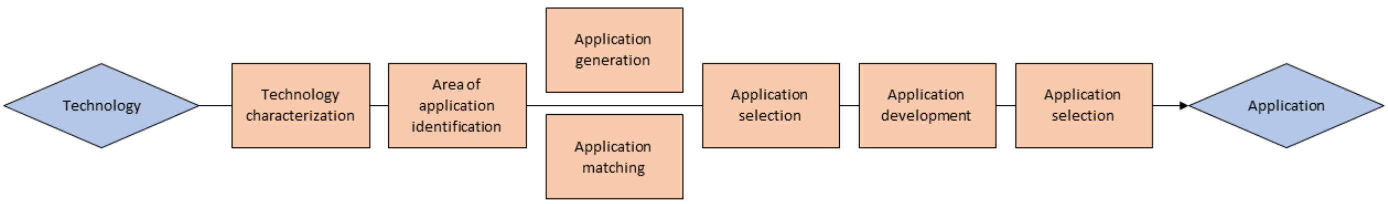

Figure 11: The developed framework, version 2.

For now, both frameworks are considered. In the coming chapters, the literature is consulted once more and the general framework created up until this point is validated and improved.

5 Frameworks from literature

As was proposed in chapter three, after the framework is created with the results of the preliminary interviews, it will be validated. The first step in the validation is the second literature review. In this chapter, the frameworks that were found in literature are described. In the next chapter, the frameworks from literature will be used in validation of the framework developed in this research.
Six frameworks have been identified in literature. These frameworks are presented in the following sections. Subsequently, a characterization of the different types of frameworks identified in literature is presented. Lastly, the chapter concludes with an outlook towards the following chapters of this thesis.

5.1 Technology-utilization-model (TUM)

In the technology utilization model (TUM) proposed by Hartelt *et al.* [8], six steps are identified to go from a technology, to a product ready to enter the market: technology characterization, task characterization, derivation of evaluation criteria, technology assessment, performance impact evaluation, and task-technology-fit conclusion and customer utilization. A graphical representation of TUM is provided in appendix G.1. This model is based on the task-technology-fit (TTF) approach developed by Goodhue and Thompson [69].

In the first step, the technology characterization, the technical aspects and the potential application/market of a technology are characterized. In the technical characterization the basic structure, physical operating principle, general functionality and workflow principle of the technology are provided. In the potential application/market characterization, feasibility and maturity of the technology are identified. On top of that, based on the technological problem the technology is addressing, the main purpose, most promising utilization possibilities and potential application fields should be described.
Lastly, the authors propose some methods to employ in this phase: consulting experts, reviewing the technical press, visiting trade fairs and analyzing technological alternatives.

The second step, the task characterization, the technical problem that has to be solved by the technology (on itself or imbedded in a larger system) has to be characterized. The authors again propose some methods to employ in this phase: interviewing application experts, involving lead users, conducting internet inquiries, observing and analyzing concrete use cases.

In the third step the criteria that will be used to evaluate the task-technology-fit have to be identified. The authors propose to do this via questioning technology users, to obtain their perspective on the technology (since this perspective is decisive for the success of the technology). The future needs of the potential customers also have to be taken into account, by involving lead users or utilizing scenario techniques.

In the fourth step, the technology assessment, the technology under consideration is compared to existing alternatives. The alternative technologies can be compared using the criteria identified during the previous step. The method proposed for this step is consulting technology experts in the field (to increase the result validity, consult more than one expert, scrutinize and cross-check the results).

The fifth step is all about the customer needs. By weighing the evaluation criteria identified in step three from a customer perspective, the users' influence on the task performance can be increased. The authors propose to accomplish this weighing by interviewing technology users, lead users or application experts.

In the sixth and final step, the final task-technology-fit is assessed by taking the sum of the multiplied evaluation scores from the third step with their respective weights from the fifth step. Or in formula:

$$TTF_x = task - technology - fit\ of\ technology\ x$$
$$TE_n = score\ on\ the\ \mathrm{nth}\ criterion\ (step\ four\ of\ the\ framework)$$
$$W_n = weight\ assigned\ to\ the\ \mathrm{nth}\ criterion\ (step\ five\ of\ the\ framework)$$
$$TTF_X = \sum_{i=1}^{n}(TE_i * W_i)$$

Applying this formula to all technologies considered provides a quantitative ranking of a technology relative to its alternatives. The relative value can be used to predict relative likelihood of utilization by customers.

Lastly, the reliability of the framework: the framework is developed from the task-technology-fit approach developed by Goodhue and Thompson [69]. How the TTF has been extended to yield the framework described in the paper has not been elaborated. The framework has been tested on one technology, and two applications/use cases have been described in the paper. In both use cases, an application is identified at the start of the framework and the framework mainly involves the selection or comparison of this application to rival technologies. The workings of the framework are demonstrated, but the results have not been backed up by actual implementation data (aka no real-world evidence of the reliability of the method is provided).

5.2 Technology-push lead user concept (T-PLUC)

The technology-push lead user concept developed by Henkel and Jung [14] builds upon the lead user concept developed by Von Hippel [65]. The T-PLUC is presented as a five-step method to creating a product concept, starting at a technology and going through trends, markets and lead users. A graphical representation of the method can be found in appendix G.2. A sixth step is not mentioned as such but is described in the text: lobbying. Each phase is described in the paper, but only very minimally, as can be seen in the next part of this section.

In the first step, the “merits of the focal technology are determined”, which means the essential information on the considered technology is gathered.

In the second step, the method looks at how the specific properties of a technology match to a certain trend in the real world. As an example, they offer a material that is both strong and light, which they couple to the trend of more delicate products.

In step three, the relevant industries and market segments for the trends are identified.

In the fourth step, lead users are identified.

In the fifth step, these lead users are invited to a workshop to devise novel product concepts.

In the unofficial sixth step, the lead user(s) and/or the technology provider approach product manufacturers with their devised concepts and lobby for their realization.

Lastly, the reliability of the framework: the developed T-PLUC framework is an extension of the already existing lead user concept.
Different in the paper on the T-PLUC framework compared to other frameworks is the section on “conditions for T-PLUC to work”, effectively discussing the limitations of the framework.

The framework has been tested with three case studies and one real world example. For the case studies, comments are made on the newness and non-obviousness of the application possibilities found with the method. However, how successful these applications are or would be has not been mentioned. The conclusions of the real-world example concluded that particularly the workshop with the lead users at the end of the framework turned out to be a big success. On top of that, the method helped to "court a development partner", which effectively yielded a manufacturer for the technology in a new application.

5.3 Total system approach to technology push (TSA)

In a paper by Souder [20], an eight step, total systems approach to technology push is provided, based on 15 successful cases of technology push innovation. The eight steps are: characterization, embodiment, peripheral applications and substitute uses, internal fitting and broadcasting exercises, technology and market scanning, trial and re-trial processes, selection and target applications, and expanded application work. A graphical representation of the method is provided in appendix G.3.

According to the paper, in the first step, the characteristics of the technology are defined, while bearing in mind the potential applications where these characteristics might provide a benefit. It is remarked that at this stage, it is often impossible to know all (relevant) characteristics of a technology. The author proposes to feed results from later steps back into this initial step. On top of that, it is remarked that this step is best carried out in a group setting, with a interdisciplinary team of R&D, marketing and manufacturing personnel.

In the second step, the goal is to find a way to embody the new technology in an already existing product or process. This is done to make the technology seem more familiar/less threatening to potential users. The author proposes to do this phase with interdisciplinary teams, focus groups with potential users, morphological analyses and the SAMM (sequence-attribute modifications matrix) method. The author remarks that this is the first step where users are involved. This should be treated carefully, since by trying to satisfy users too quickly, some potentially valuable aspects of the technology might be overlooked.

In step three, the goal is to find an application outside of the "spotlight"/mainstream. This way, users can be eased into the technology. A good place to start is substitute uses, where the technology can replace (part of) an existing component or process. Again, users are involved.

The next step is about communicating the technology within one's own organization. By ensuring everyone knows about the technology, a new source of potential innovation and synergy is created. The author purposes to do this by assembling *ad hoc* brainstorming and idea-fitting teams, with members from all over the organization.

As can be seen in appendix G.3, the fifth step is done in parallel with the fourth step. Step five is not really a concrete process, but rather an awareness. According to the author, it is important to constantly keep track of the potential opportunities that a technology has, with a continual scanning effort.

Step six is done in parallel with the previous steps too. This phase is about going to the customer with the technology, to prove its worth and create dissatisfaction with the *status quo*. This provides valuable input to further developed the technology. The author remarks that good customers relations are important for this step.

The following step is a decision that has to be taken on which application to pursue. In a company perspective, this decision is taken by management. A decision could also be to put the technology on the shelf. This does not have to be bad, as long as the technology is re-examined from time to time.

The last step is a reminder to repeat the previous seven steps. According to the author: “It is only through these additional applications that the technology becomes more fully embodied, diffused and successfully applied in ways that can spawn further needs and stimulate other technologies.”

Lastly, the reliability of the framework: the framework was developed by taking into account results from a literature survey on technology push innovation, the analysis of 15 successful examples of technology push innovations and the analysis of interview results obtained by interviewed R&D managers from 21 IRI (industrial research institute) member firms. The firms were selected to represent a cross-section of industries, R&D activities, firm sizes and R&D budget.
The framework was not further evaluated or tested after its creation.

5.4 Method for the identification of alternative technology applications (ATA)

The method developed in the paper by Bianchi *et al*. [47] borrows from the TRIZ methodology that is discussed in appendix F.5. The essence of TRIZ is explained in the paper using a citation from Domb: “somebody, someplace, has already solved your problem, or one very similar to it” [70].

The method developed in the paper by Bianchi *et al.* uses an inversion of the TRIZ method, similar to the inversion presented by Glaser *et al.* [71]. A graphical representation of this method can be found in appendix G.4. The authors propose to abstract the technology to an appropriate level, find a general problem this abstraction could solve and translate this general problem into (a) specific application(s). The developed method is organized in five steps: definition of the technology’s requirements, TRIZ-based analysis of the technology, selection of the abstract problems, identification of the alternative technical applications (a.t.a.) and strategic positioning of the a.t.a..

In the first step, information on the technology is acquired and formalized. The paper suggests to use the technology description framework by Linton and Walsh [55]. For more on this framework, see appendix H. Bianchi *et al.* propose the questions in the technology description framework can be answered by consulting technical documentation, interviewing technology development leaders and surveying technical personnel working on the technology.

The second step is about abstracting the technology. The paper proposed two TRIZ-based tools to generate a conceptual view of the technology: function analysis (FA) and evolution potential analysis (EPA). The FA method is used to identify the basic function of a technology by scoring the technology on several basic functionalities with a four-point scale: low, medium, high and maximum. An example is provided of the usage of the FA method in the form of a scoring table, provided in appendix G.4. This score indicates how well the technology performs this function, in comparison with competing technologies. These scores can be used in the subsequent step to identify an abstract problem that could be solved by the abstracted technology. The EPA method is a method to assess the (potential) evolution path of a technology by comparing the current, abstract state of a technology with known evolution trends identified within the TRIZ. Where the concept of technology evolution does fit in the TRIZ is unknown at this point, but also not within the scope of this research. Again, an example of the usage has been included as a table, which can be found in appendix G.4. The paper recommends consulting TRIZ experts to verify whether the methods have been applied correctly and the results been interpreted correctly.

In the third step, the goal is to find general problems that could be solved by the abstracted technology. According to the authors, these technologies directly flow from the FA and EPA methods. The functionalities for which a technology scores “maximum” are the most interesting to look at. Likewise, it is most interesting to select the paths of evolution in which the technology has already evolved considerably. These functionalities and evolution paths are used to find viable general problem areas. How the subsequent abstract problems are identified by the method is not specified in the paper.

In the fourth step, the abstract problems from the previous phase are contextualized into areas of application (specified as “alternative sectors in which the technology can be applied” in the paper) and specific applications. This is done through a method described by Mann [72], where five to ten catchwords are generated for each abstract problem found in the previous phase. These catchwords are subsequently used to search in different knowledge databases and repositories, to find specific application related to these catchwords. The resulting information can be used as an idea pool to search for a.t.a.. The list of applications can be filtered by discarding all the results that are not compatible with the technology requirements gathered in the first step of this method. The paper proposes that at the end of step 4, the user should have roughly 20 to 30 promising a.t.a..

In the last step, the 20 to 30 promising a.t.a. have to be prioritized. The authors propose to use a method developed by Dean and Nishry [73]. According to the authors, they chose this method because it allows consideration of multiple technical and market perspectives, it is simple to interpret, quick in use and it fits the quantitative nature of the method thus far. The authors identify three criteria that should be used in assessing the a.t.a.: technical feasibility, market attractiveness and innovativeness. The a.t.a. achieve a score on each of the three criteria and can be plotted in a market attractiveness vs technical feasibility space, with the area of the circle representing the innovativeness (see appendix G.4). Now the a.t.a. can be selected that best fits the goals of the users, with respect to the three evaluation criteria just described.

Lastly, the reliability of the framework: according to the authors, the framework presented in the paper has been developed in close collaboration with a highly innovative Italian SME. This SME developed a patented packaging technology which they wanted to license outside of the packaging industry to increase revenue. To accomplish this, the SME decided to work together with the two authors of the paper. As sources of information, interviews, internal documents and publicly available data have been accessed. Apart from the collaboration with the SME, inspiration for the developed framework was gathered from the framework developed by Glaser and Miecznik [71].
Since the method was developed to find a.t.a. for the packaging technology, the method was used on this technology. The method returned 20 alternative applications, of which five were identified as promising by the management of the company. Two of the applications have been “pursued” and have started to generate revenue for the SME. Contrary to previous frameworks, the paper demonstrates that it can generate alternative applications that can (at least) generate revenue. This does not prove the framework generates groundbreaking innovations, but it does show that it is to some extent capable of what it claims to be capable of.

5.5 Normative model for idea generation and opportunity recognition (NGR)

In an article by Linton and Walsh [55], no framework is developed, but more so the literature available on the early stages of new product development is reviewed and a summary in the form of a framework is provided. This framework has not been depicted in the paper, but an interpretation has been made and presented in appendix G.5. It is mentioned that the article focusses on opportunity recognition for technology-push products, and thus they do not focus on market orientation.

The article identifies five phases in early product development: ideation/idea generation, idea evaluation, market orientation, market interaction and uncertainty reduction. Only the first two phases are considered in the paper. The paper focusses on idea generation, since that is the most important issue in process, according to the authors.

Strangely enough, technology description has not been identified in these five phases, while a considerable part of the paper is dedicated to the presentation of a technology description framework (depicted in appendix H). In the technology description, interesting characteristics and potential functions of these characteristics are identified.

For the idea generation phase, Linton and Walsh borrow from Goldenberg *et al. [74]*, who classify five different idea generation methods: need spotting, solutions spotting, mental invention, market research for new product and following a trend. Need spotting is about identifying a market need and developing a product to address this need, while solution spotting is the other way around (a product is defined, and a suitable application is identified). Solutions spotting is something that the framework developed in this thesis tries to accomplish. How solution spotting has to be performed is not further elaborated in the paper by Goldenberg *et al.*, nor by Linton and Walsh.
Mental invention is based on an internal cognitive process, a decision is made to innovate.
Market research is similar to need spotting, the difference is that with market research a market analysis is performed in which the unsatisfied need is identified, and the subsequent innovation is done to address this need.
Following trends is about creating a product that is a logical extension of an ongoing market trend.
According to the authors, need spotting, market research and following trends are not suitable methods for the opportunity recognition from technology-push products, since the methods require external market information before the product development. Solution spotting and mental invention are the ways to go with technology-push.

In the idea evaluation phase is briefly considered in the paper. The authors remark that “There are various methods for idea-screening, but best practice based on empirical evidences remains elusive.” The only information provided about the content of this phase is that it is critical to interact with the market. Or as stated by Goldenberg *et al.*: “The development process for successful products is characterized by frequent and in-depth customer interaction at all levels and throughout the development and launch process.”

Lastly, the reliability of the framework: the framework was created building on several pieces of research, even borrowing some of the phases of the framework entirely from different pieces of research.
The described framework makes a distinction between disruptive and sustaining technology (this distinction is not relevant in the interpretation of the paper for the purpose of this research). For both types of technology, a case is described of a technology that finds potential applications through the framework. However, how successful these potential applications are or would be has not been tested.

5.6 New concept development model (NCD)

According to Koen *et al.* [75], the innovation process can be divided into three parts: the front end of innovation (also called the fuzzy front end, FFE), the new product development process and the commercialization. This process is depicted in appendix G.6. They remark that, although the decisions made at the front-end part are determinant throughout the rest of the innovation process, the front end has not been researched much.

According to Koen *et al*., meta-analyses have identified over 250 articles on the product development phase that have been published since 1979, but only a few on the front end. One of the studies on the front end, by Khurana and Rosenthal [76], was extended by Koen *et al.* [75] into the new concept development (NCD) model. This model can be found in appendix G.6.
In the article by Koen *et al.*, they argue that calling the front end of innovation (FEI) the fuzzy front end (FFE) has the inherent danger of incorrectly perceiving the FEI as a phase dominated by unknowable and uncontrollable factors.

The NCD model consist of five key elements that compromise the FEI, the engine in the middle the figure (fueled by the leadership and culture of the organization) and the environment on the edge of the figure. The environment consists of organizational capabilities, business strategy, the outside world and the enabling science. These same factors influence the entire innovation process. The circular shape of the figure is meant to indicate that ideas are expected to flow, circulate and iterate between all five key elements of the model. They will be discussed sequentially, but no specific order of the elements is embedded into the model.
In the model, the influencing factors represented by the black peripheral around the five key elements is compared to a marine environment. Where a healthy marine environment is needed for a healthy population of aquatic species, a healthy organizational climate is needed for a productive FEI. Examples of this organizational climate are organizational capabilities, competitor threats and regulatory changes.
Now the five key elements, or five front end elements, will be discussed:

In the opportunity identification element, as the name suggests, business opportunities that the company might want to pursue are identified. The authors suggest to use creativity methods (e.g. brainstorming, mind mapping, lateral thinking) and problems solving techniques (e.g. causal analysis, fishbone diagrams, process mapping, theory of constraints), as well as informal activities (e.g. individual insight, “coffee corner sessions”). Lastly, opportunity identification in many cases precedes idea genesis.

In the opportunity analysis element, the identified opportunities are further analysed. The paper does not describe specifically how this happens but does offer competitive intelligence and trend analyses as potential methods to use during this phase.

The idea genesis element is, according to the paper, the birth, development and maturation of the opportunity into a concrete idea. Ideas are iteratively built upon, torn down, combined, reshaped, modified and upgraded during this phase. The authors mention that direct contact with customers, other cross-functional teams and other companies or institutions will often enhance this activity. The output of this element is typically a relatively complete vision of the idea or product concept.

The idea selection element is difficult in this phase of the innovation process, according to the authors, due to limited information on and understanding of the available options. According to the authors, better selection models specifically designed for this element are needed. On top of that, idea selection should be less strict now compared to later on in the innovation process, as to let every idea grow and advance.

In the last element, concept and technology development, involves the development of a business case based on estimates of the market potential, customer needs, investment requirements, competitor assessments, technology unknowns and overall project risk.
As a bridge between the FEI and the NPPD, often a business plan and/or a business proposal is created.

Lastly, the reliability of the framework: initially, product development managers from eight different companies, together with the industrial research institute, set out to develop a set of best practises for the FEI. However, it was found that no common language or definition of key elements could be found among the eight companies. To address this, the NCD was developed.
The authors conducted a survey among 23 innovative companies to determine which elements of the NCD were most important to these companies. The proficiency of the companies with respect to the different steps and phases in the total innovation process and in the NCD framework were determined respectively (please refer to the paper by Koen *et al.* [75], page 53, to read how the proficiency was determined). The first important finding from this proficiency measurement is a higher correlation between proficiency in the NCD components and innovation than between the NPPD and innovation. In other words, the FEI likely plays are more important role in determining overall innovation than the NPPD.
Within the NCD, the opportunity identification phase and the concept and technology development phase were identified as the phases with the strongest influence on innovation (the correlation of innovation towards these two phases was the highest).
Correlation of innovation with idea genesis was not found in the proficiency tests. This seems to undermine the point of view this thesis is building (endorsing the importance of application identification). Alternatively, the authors propose the explanation that all companies, independent on their level of innovativeness, are equally bad at application identification and overall signification improvement is needed. In line with earlier discussions on the importance of application identification, this is deemed likely.

5.7 Framework characterization

The frameworks from this chapter have some defining characteristics. A first characteristic is the shape of the framework. Some frameworks are linear (TUM, T-PLUC, ATA, NGR), while others are branched (TSA) or even circular (NCD).
Another characteristic is the focus point of the framework. Some of the frameworks approach the application identification or generation process with a problem solving focus (TUM, ATA), others with a customer focus (T-PLUC, TSA). The NGR and the NCD framework have aspects of both problem solving and customer focus. The focus point of a framework can also be interpreted differently. Only the T-PLUC, the NGR and the NCD frameworks are really focussed on generating or identifying applications for “technologies” that have high impact/relevance (applications that are in the spotlight vs applications that are out of the spotlight as discussed in the TSA framework). The TSA framework focusses on applications outside the spotlight, the ATA framework on **alternative** applications and the TUM framework on a comparison of the technology with its technical alternatives.
A third aspect on which the presented frameworks can be characterized is the selection methods applied in the framework. Some frameworks have a very quantitative selection method (T-PLUC, ATA), while the others employ less quantitative selection methods. On top of that, some frameworks include market arguments/customer opinion (TUM, ATA, NGR) or potential manufacturers (T-PLUC) in their selection.
Lastly, an maybe most importantly, the frameworks from literature differ in how they treat the actual application identification or generation process. Some frameworks explicitly treat application generation or identification and provide methods (NGR, NCD), while other frameworks embed it into another phase of the framework (TUM, T-PLUC, TSA). In the ATA framework, application matching is used to find applications.

In the next chapter, the frameworks from literature will be compared to the framework created in this thesis. With the input from the frameworks from literature, the framework from this thesis will be validated and improved.

6 Framework validation

In this chapter, the three steps in the framework validation that have been described in figure 3 will be treated. First, the frameworks found during the second literature review will be compared to the framework created with the results of the preliminary interviews. After that, the results of the second interview series will be presented. Thirdly, the results of the expert discussion will be presented. Lastly, the chapter will be concluded and an improved version of the framework developed in this research will be presented.

6.1 Second literature review

In the first section of this chapter, each framework from literature is compared to the phased framework depicted in figure 12. To visualize this comparison, a table comparable to table 11 is depicted below. In section 6.1.2, some elements from the frameworks from literature that have not been mentioned yet will be discussed.

6.1.1 Comparison

In this section, the frameworks described in chapter five will be compared to the five (or six) phased model synthesized in chapter 4 (see figures 12 and 13 respectively).

	IGP	AAP	AGP/MAP	ASP	ADP
TUM	X	X	X		
T-PLUC	X	X	X		
TSA	X		X	X	
ATA	X	X	X	X	
NGR	X		X	X	
NCD		X	X	X	X

Table 12: A comparison of the framework from literature with the identified phases of the framework created in this thesis.

* please refer to section 4.1.5.2 for an elaboration.

6.1.1.1 Information gathering phase

As can be seen from table 12, the information gathering phase is one of the phases most prominently featured throughout the frameworks described in literature. Only the NCD framework does not explicitly have an information gathering phase. This was unexpected, considering the detailed description of the other phases of the NCD framework. It is believed that information gathering is needed in/part of the NCD framework, since relevant information on the technology will be needed in subsequent phases.

Concluding, the information gathering phase has been recognized in literature as part of a framework to find applications for technology. However, following the trend in literature, the phase will be renamed to characterization, where both information gathering and information presentation (what and how) are taken into account. A method for technology characterization has to be provided, probably in the form of a list of questions to answer. This phase will get data from consulting experts (dialogue with experts), reviewing the technical press (literature search), visiting trade fairs and analyzing technological alternatives. Lastly, it will be considered whether market arguments will be included in this phase and whether the phase will be repeated throughout the framework. An update version of the information gathering phase is provided in figure 11, building on the representation created in figure 2. Due to the uncertainty whether market arguments (and thus customers) will be included in this stage of the framework, any market or customer related affair have not been mentioned in the figure.

On top of that, the experiential characterization elements have been removed for now, since only one of the interviewees mentioned it and no literature backs up the idea of an experiential characterization (N.B. this could be due to a lack of the right literature instead of a lack of support in literature).

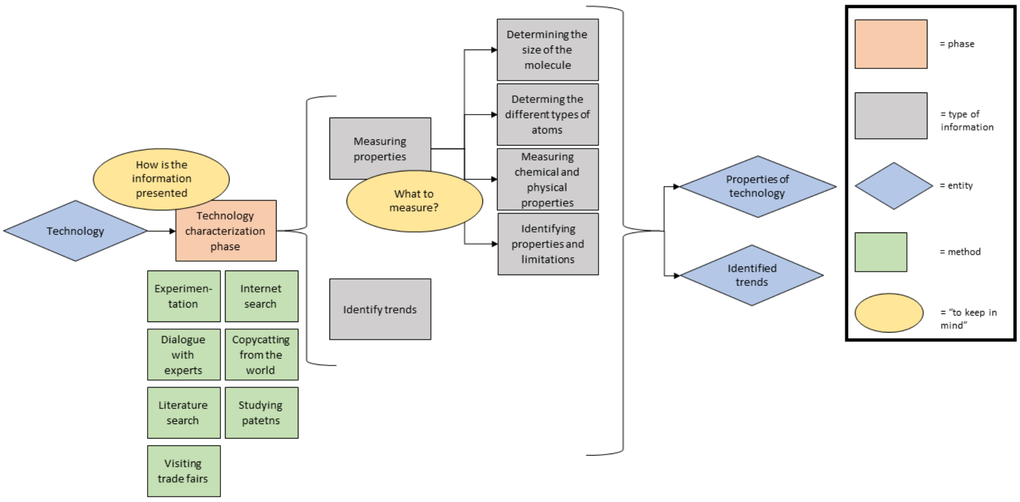

Figure 12: The improved information gathering phase.

6.1.1.2 Area of application identification phase

As can be seen from table 12, the area of application identification phase has only been featured in four of the six frameworks described in literature. Even in the four articles that have been checked in the AAP column of table 12, most framework do not mention the area of application as such.
The only framework that does mention area of application is the ATA framework. In the paper on the ATA framework, TRIZ based methods are used to identify an area of application and subsequently, actual applications. Although specific tools have been described, no explanation is provided for the methods, nor is any reference made to literature in which these tools can be reviewed.

Concluding, the area of application identification phase is recognized by some of the literature as a part of the application generation/identification process. An elaborate description of the methods that could be used in this phase is missing in (most) literature. The methods that are mentioned are creativity techniques and problems solving techniques. Another paper mentions the data sources: consulting experts, reviewing the technical press, visiting trade fairs and analyzing technological alternatives. The relevance of these methods and data sources has to be checked, especially in the context of the framework developed in this thesis.

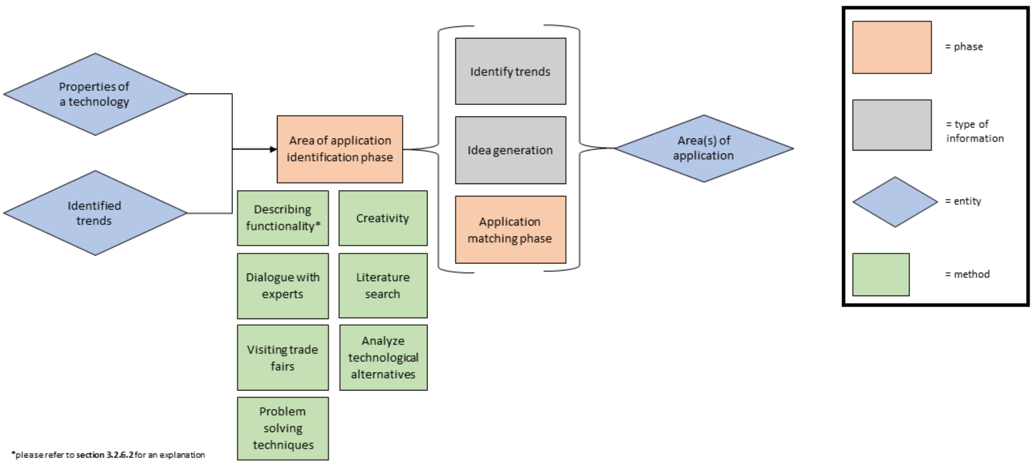

Figure 13: The improved area of application identification phase.

Overall, it is believed the literature, especially in combination with the results of the preliminary interviews, support the area of application identification phase enough to keep the phase part of the framework developed in this thesis. In figure 14, an updated version of figure 9 in section 4.2.3 has been provided. The methods described in the literature and the connection between area of application and trends have been added to the figure. On top of that, the starting point has been changed, following the described output of the technology characterization phase from the previous chapter.

6.1.1.3 Application generation or application matching phase

Similar to the information gathering phase, the application generation or matching application phase has been featured in most frameworks. However, it was found that often in literature this phase is described as application identification in stead of application generation. This points to a different origin of the applications; generation is really a process of creating new applications, while identification points more towards finding already existing applications. It is expected that the two different depictions of this phase lead to fundamentally different methods. It might be that one of the two is chosen as dominant (generation or identification), or that they might exist next to each other.
The only framework in which applications are generated is the T-PLUC framework. In this framework, lead users are identified and invited to participate in a workshop. During this workshop, potential applications are generated (although how these applications are generated has not been mentioned in the paper, one might expect some form of a creative process).

Concluding, application generation or identification has been identified in literature as a part of the framework to find application for technology. Matching has been featured less in the considered literature.
Although application identification has been recognized, the phase is often treated superficially. Applications often suddenly appear during a certain phase of the considered frameworks, without specific attention as to how the applications came to be. The notion that application identification is treated superficially is in line with the conclusion drawn by Strøm [1].
Methods differ significantly between different pieces of literature. Creativity is featured in some of the frameworks, but compared to the preliminary interview results, underrepresented. Some interesting notions raised in the literature that might be used in the framework developed in this thesis are the involvement of lead users in the application identification phase, the idea of easing users into a new technology by searching for substitute uses or peripheral applications and lastly, the connection between the phases of application identification/generation and application development.
In the figures 15 and 16 respectively, the application identification/generation phase and the application matching phase have been depicted. Some differences in the figures compared to the figures 5 and 8 are the removal of the experiential characterization inputs (in line with previous section), the separation of application generation into identification and generation, the involvement of lead users in the creativity process of application generation and lastly, the inclusion of the notion of user perception.

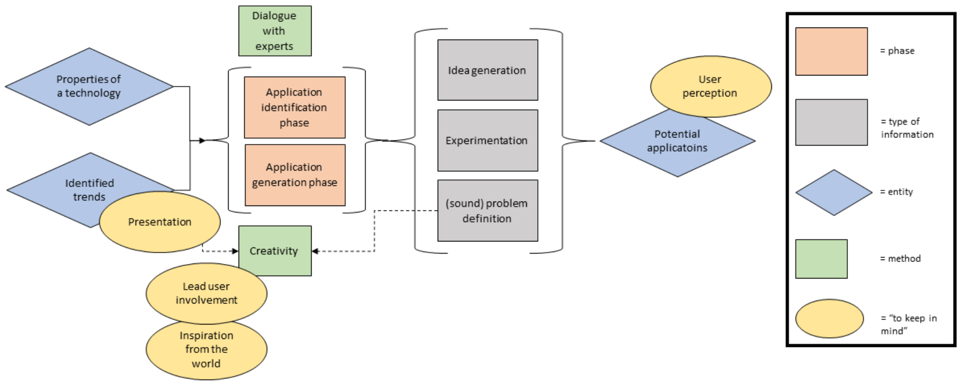

Figure 14: The improved application generation of identification phase.

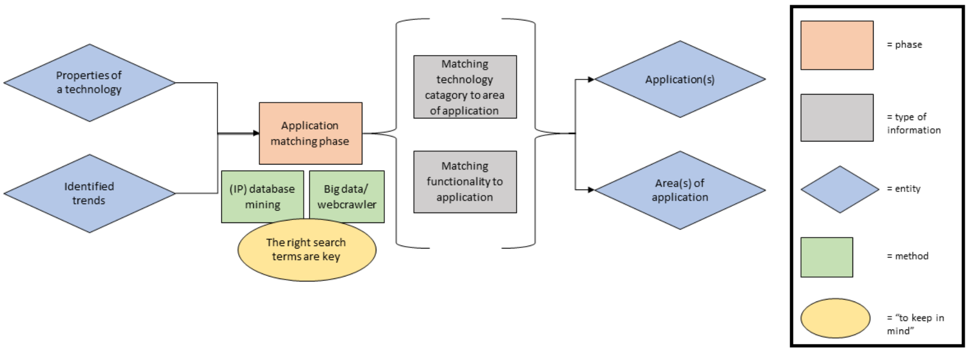

Figure 15: The improved application matching phase.

6.1.1.4 Application selection phase

As can be seen from table 12, application selection is featured in four of the six frameworks from literature. Although a selection phase has not been featured in the second and third framework, there are some things we can learn from these frameworks.
In the TUM framework, the task-technology-fit method is used as a **technology** selection method. In the framework created in this thesis a quantitative selection method might be desirable in the framework (to improve the overall objectives of the framework). The proposed comparison method (TTF) might be altered to create a technology-task-fit or technology-application fit, for example by calculating a TTF value for every alternative potential application.

In the last phase of the T-PLUC framework, the potential application concepts devised in the framework are presented to potential manufacturers. These manufacturers subsequently select the potential applications they see as worthwhile (which could also be none).
It might be good to consider who to incorporate in the selection phase to ensure the selected application best matches the goal of the user of the framework (profitability, best solution, etc.).

Concluding, application selection is recognized by most literature as a step in their respective frameworks. It is only completely skipped over in the TUM framework (the T-PLUC method at least proposes to let potential manufacturers select their favourite potential application).
Two quantitative selection methods are proposed, being the TTF method and the methods developed by Dean and Nishry [73]. To improve objectiveness of the developed framework, it is likely that a quantitative selection method will be used. However, which quantitative selection method is optimal in this framework is unknown. This should be researched in more detail.

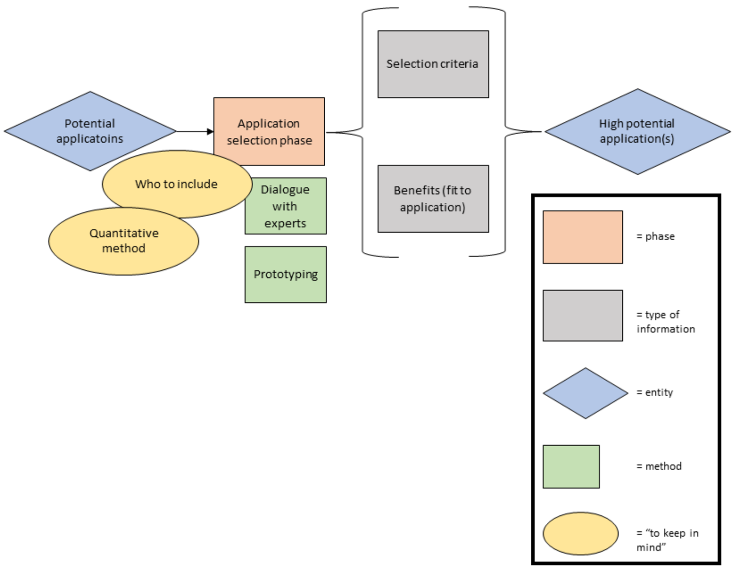

Figure 16: The improved application selection phase.

Lastly, one of the frameworks involves the potential manufacturers in the selection process, while another framework mentions the importance of market interaction. It might be worthwhile this think about who has to be included in the selection phase.
In figure 15, an overview of the selection phase is presented, building the selection phase presented in figure 4. The most important changes are two questions/thing to keep in mind: who to include, and the notion that a quantitative selection method is advised.

6.1.1.5 Application development phase
The application development phase is the least represented in literature, only being featured in one of six frameworks, as can be seen from table 12. However, it is believed this does not mean that the phase is necessarily not part of the framework developed in this thesis. Rather, it is believed that the frameworks in literature stop their process earlier than the framework described in this thesis. Given the proposed goal of the framework developed in this thesis, the phase will be left in the framework, even with the bad fit seen in table 12.

No figure of an “improved” phase has been added, since it is believed the literature does not mention important aspects that have not yet been included in figure 5 in section 3.2.1.4.

6.1.2 Extra’s from considered frameworks
Some elements from the frameworks in literature have not been discussed (enough) during the description and comparison of these framework. These elements will be (further) discussed in this section.

6.1.2.1 Customer inclusion
Several frameworks talk about the inclusion of customers or users in the process of application generation or identification for technology. The TUM framework, the T-PLUC framework, the TSA framework and the NCD framework all include some form of (lead) user involvement.

Customer, consumer or user involvement is something that has been studied extensively in design methodology, evident from the vast amount of methods that exists to accomplish user involvement: quality function deployment (QFD) [77-79], beta testing [80], concept testing [81-83] and consumer idealized design [84]. N.B. some methods can be combined.
A paper by Kaulio [85] provides a (somewhat outdated) overview and comparative analysis of these methods. The different methods are compared on two dimension: depth of user involvement (design for, design with or design by) and amount of user involvement throughout the process (five phased design process: specification, concept development, detailed design, prototyping, final product).

N.B. on a first glance, this five phased design process does seem to be similar to the phases of the framework developed in this thesis. A challenge for this thesis in dealing with design methodology frameworks is the fundamental difference in start and ending point of the two approaches. In this thesis, a framework is developed in which a technology finds an application (problem to solve), while in design methodology, a problem is solved by identifying or designing the appropriate technology.

In the framework developed in this research, users will likely be involved. On which point in the two dimensions provided above has to be decided. Some frameworks in literature point to a “design by” and involvement as early as “specification” (TUM), while other frameworks are inclined towards a less rigorous involvement of users (TSA). The subject of customer inclusion will return during the expert discussion.

6.1.2.2 Iterative framework
As discussed before, not all frameworks from literature are linear. The TSA framework is branched and the authors propose to go through the framework multiple times. The NCD framework a set up completely circular/random, with no specific order given to the identified phases of the framework.
In this section, a review of the linearity of the framework developed in this thesis is presented. In figure 16, a framework concept is presented that addresses both the linearity and the order of the development and selection (addressed in section 4.3, figures 11 and 12).

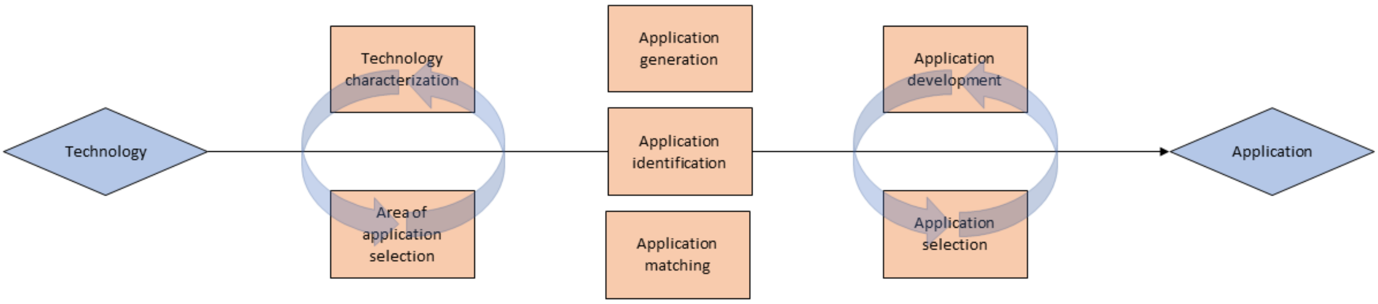

Figure 17: The developed framework, version 3.

It is proposed that by going through characterization and area of application identification iteratively, a process can be achieved in which information leads to a first estimate in potential areas of application (on a meta level), which leads to gathering of information relevant in those areas of applications, leading to a further specification of the area of application, etc., until a specific enough area of application is reached.
In the other iterative section, a first selection in the applications devised in the previous section and a subsequent preliminary development of these applications leads to more information on the alternative application possibilities and thus to better information needed in the selection process. This continues until one or a few of the "best" applications remain.
Coming back to previous section, it is expected that at least the last iterative section will have user involvement: by including user involvement in the development and selection, to applications most appealing to potential customers have a higher chance of making it through the selection steps.

N.B. whether the other two phases will include customer involvement will, as mentioned before, be addressed during the expert discussion.

6.2 Second interview series

As discussed before, the second step in the validation of the framework is a second series of interviews. Interpretations of each interview are provided in appendix I.
Since the two goals of the second series of interviews were validation and translation (to organic chemistry), the experts were chosen based on their affinity with (organic) chemistry. The "translation" section of the results will be treated in the next chapter. The "validation" section will be treated here.
Throughout the interviews, some improvements were made to the framework, so not all interviewees saw the same framework. Which framework was seen by the interviews has been reported in each interview report in appendix I. N.B. the framework provided in appendix I might look somewhat different compared to the frameworks presented throughout this thesis. This is due to the fact that it was decided after the interviews to choose a different style in the depiction of the framework.
The most important results of the interviews have been summarized in table 13.
Most interviewees seemed to agree with the developed framework, candidate 13 even stating that he recognizes the process from his practical experience. Only candidate 11 did not comment on the correctness of the framework, stating that the framework is too general to be practically applicable.
Several improvements were made to the frameworks following the results from the interviews. Some of these improvements have been retrospectively added to the frameworks in the previous chapter. These improvements include: a clear starting and ending point for the framework and the change of "area of application selection" into "area of application identification". A change that was not respectively added is the change of "application development" into "application validation". This change is implemented in figure 17 below.

Interviewee	Remark
Candidate 7	Not everything has to be in one company. My recent experience, the application was produced by another company after I showed the working principle with a mock-up model.
Candidate 7	Once the workings of an application have been shown, the market has to be developed.
Candidate 7	Change “area of application selection” to “area of application identification”.
Candidate 9	The process is not always structured and/or funneled, but iterative, cyclic or random.
Candidate 9	You need to go through the application generation or identification several times, each time you might look at different properties and generate/identify different applications.
Candidate 9	Often the most profitable applications are discovered by accident.
Candidate 11	Provide a clear starting and ending point for the framework.
Candidate 11	The framework is too general to be practically applicable.
Candidate 12	Framework is not readable without further explanation.
Candidate 12	Serendipity is an important aspect of the process, especially in application identification.
Candidate 13	Change “application development” into “application validation.

Table 13: Important statements from the second interview series about the general framework.

The importance of a clear indication of the beginning and end of framework is shown by the first remark from candidate 7 in table 13: he implicitly imposes that my framework continues after the workings of an application has been shown, which is not the case.
The two remarks by candidate 9 depicted in table 13 led to the realization that the developed framework is not a summary of all possible ways in which technology can find an application. The third comment by candidate 9 and the second comment by candidate 12 presented in table 13 are nice examples of this: there are application that are identified or generated in a serendipitous way (aka by accident). This might be an excellent way to find (profitable) applications. However, this has not been incorporated in the framework, because it is not workable in a systematic setup.
Lastly, during the interview with candidate 7, the inclusion of market arguments was touched upon. Following the occasional mention of market arguments throughout this thesis (preliminary interviews, literature and just now), the questions whether and if so when the market has to be included will be addressed during the following expert discussion.

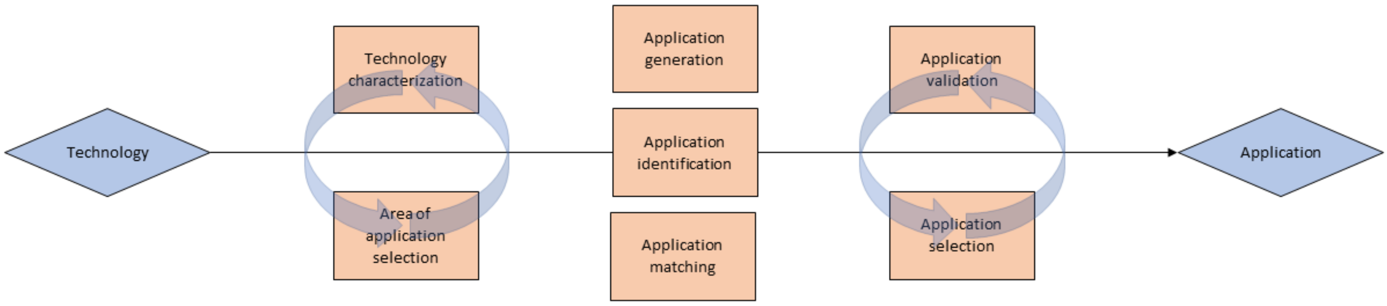

Figure 18: The developed framework, version 4.

6.3 Expert discussion

In the concluding phase of my master thesis, a discussion was held with candidate 4, candidate 10, and candidate 14 (the selection of these candidates has been discussed in section 3.2.3). During the discussion they were shown the framework depicted in figure 19.

Subsequently, a discussion was started based on three questions:

- What do you think about the framework?
- What do you think should be the order of the different identified phases?
- What is your take on lead-user/market/industry inclusion?

The participants indicated that they do not think the framework is as linear as depicted in the figure 19. A proposition is made that the entire framework has a circular shape, with all phases happening in random order, a random number of times. On top of that, all participants agreed that the starting point for this framework is not “technology”, but rather something like “scientific knowledge”. The ending point of the framework than could be “technology”.
The complex nature of technology was also discussed during the interview. Although somewhat philosophical, the discussion is relevant for this thesis, since it has been found previously that an unambiguous scientific definition for technology does not exist. Candidate 4 defines technology as “applied knowledge (scientific and heuristic), a technology only exists in an application”. Following this definition, a framework to find applications for a technology does not make sense, since the application is already inherently part of the technology.

It does not make sense to consider a single piece of scientific knowledge when looking at its transformation into technology. The scientific knowledge will always (have to be) embedded in a larger socio-technological system.
The existing technology should be part of the framework, to show where or how the evolving scientific knowledge will fit within this (collective of) existing technology.
A last aspect discussed is the societal need and acceptance. If the scientific knowledge does not fulfil a certain societal need or is not accepted by society, it can not fully involve into a technology. The societal need does not need to be a current need, it could also be a future need, that is created by introduction of the new scientific knowledge/technology. N.B. the identification of a societal need is also needed to obtain funding for a research and/or development project.

6.4 Framework update

The linearity of the framework was debated in (some of) the interviews and in the discussion. Several respondents postulate that the framework should be more cyclic than it is now. An interpretation of this idea is provided in figure 20.

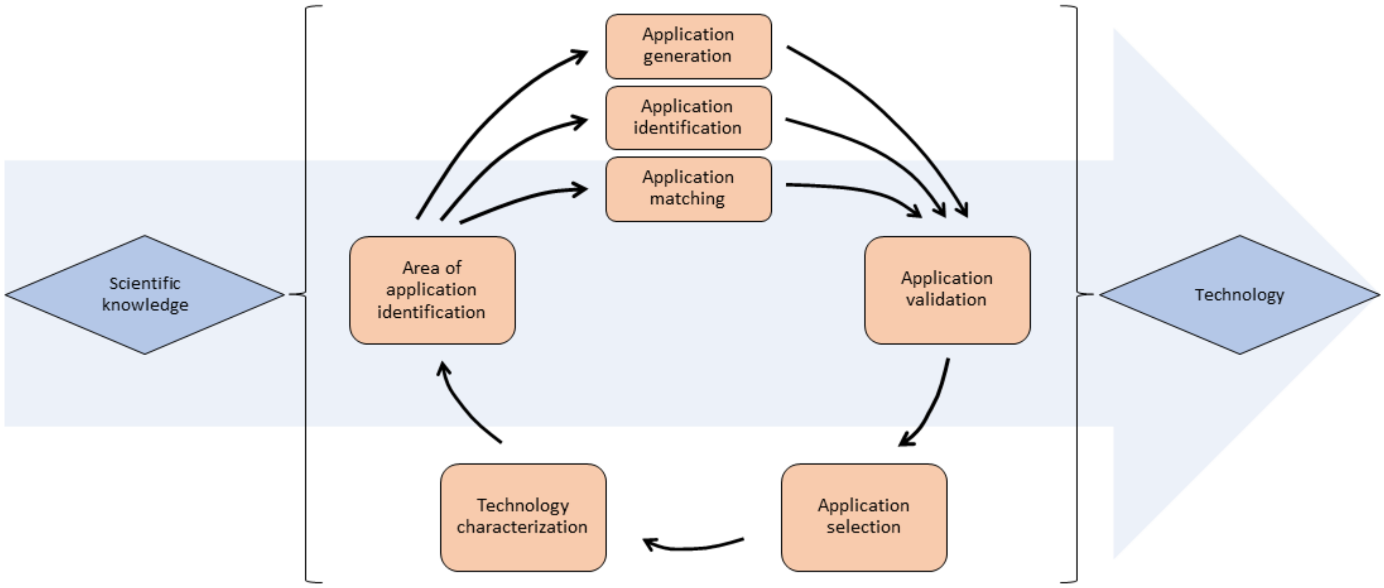

Figure 19: The developed framework, version 5.

Please note, the identified phases can separately take place an unknown amount of times. This mean that one cycle does not need to include all phases, each cycle can have a different composition.
Other changes proposed in this chapter have also been incorporated in figure 20: the information gathering phase has been changed to technology characterization phase, application identification has been added (back) to the framework and the experiential characterization elements have been removed from the framework.
In the discussion chapter, the framework will be updated and presented one last time.

6.5 Concluding

In this chapter it was found that the fit between the framework developed in this thesis and the frameworks available in literature is reasonable. In the literature considered, application identification has been treated to some degree, but compared to other phases in the framework, it does seem superficial. This is in line with the conclusion drawn by Strøm [1]. This does not mean application identification is not identified as a crucial step in technology commercialization. As stated by Hartelt *et al.* [8]: “In contrast to market-pull innovations, potential market opportunities and application fields are initially unknown in the case of technology-push. A major driver of market success is the ability to identify and exploit these opportunities”.

Considering both the results from the second interview series and the expert discussion, the framework developed in this thesis does make sense, but only with a provided context. There is a striking difference in the recognition of the general tendency of the framework in the second series of interviews and the discussion. It is postulated this is due to the context that is provided for the respondents of the second interview series, but not for the participants of the discussion: organic molecules. “Organic molecules” is much more concrete than “technology”.
To overcome this difference, it was proposed during the discussion to change the starting point of the framework. Instead of a framework to find applications for technology, the participant in the discussion proposed to instead make a framework to find applications for scientific knowledge (effectively changing the term technology into scientific knowledge). This will be further addressed during the discussion.

In the next chapter, the framework translation will be discussed. Originally, the plan for this thesis was to deliver a translated framework. However, due to time limitations, only methods that could be used for translation are proposed in the next chapter. And updated version of figure 3 is provided below. The molecule from my first master thesis will not be used to test the framework, but rather as a showcase of how a translated framework might work.

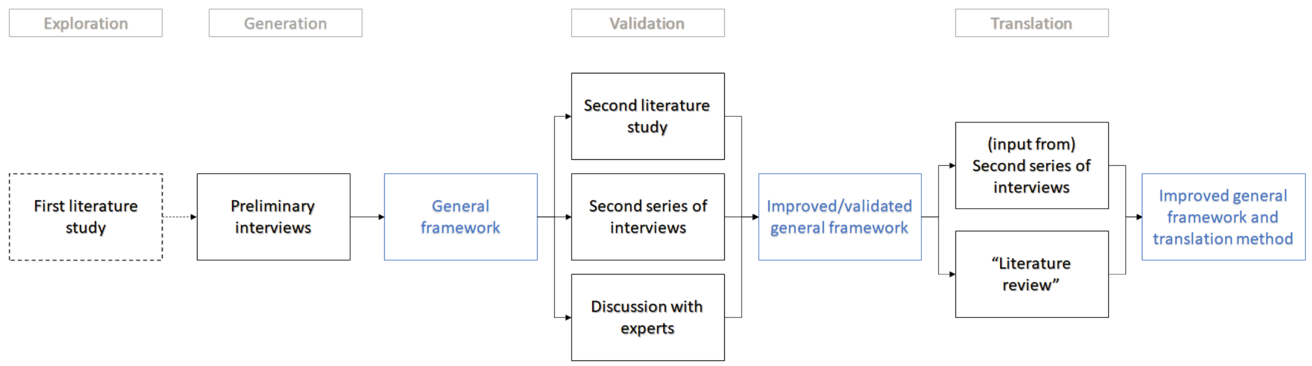

Figure 20: Updated methods for the creation of the general and specified frameworks, taking into account translation.

7 Translation

In this chapter, methods are provided to translate the general framework for application generation or identification to a specific framework that identifies applications for organic molecules. The provided methods can be used to translate the framework from figure 19 in section 6.4 into a framework like depicted in figure 21 (different starting point).

7.1 Second interview series

The setup and candidate selection for the second interview series was discussed in section 3.2.2. As mentioned before, interpretations of the interviews are available in appendix I. The results with respect to the translation of the framework into a framework for organic molecules are discussed here. The most important results of the interviews have been summarized in table 14.

Interviewee	Remark
Candidate 7	As a chemist, you are probably already operating in a certain category of molecules.
Candidate 7	After determining structure and properties, you need experts to generate potential applications.
Candidate 9	Three ways to characterize organic molecules: - On a meta level, starting from elemental composition moving into functional groups. - Based on characteristics/properties. Based on the interactions with the environment.
Candidate 9	Consult your organic chemistry book to find a classification method for organic molecules.
Candidate 9	Price can be a quick selection mechanism for organic molecules in certain areas of application.
Candidate 11	To translate the framework, consider the functionality and value of the molecule under consideration.
Candidate 12	Determining a "minimal set" of properties you need to measure to instantiate a area of application identification process is very difficult, each category of organic molecules has its own important characteristics to measure.
Candidate 12	The first information you want on an organic molecule is the structure.
Candidate 12	When the structure has been determined, subsequent measurements might be solubility, after that thermic and physical properties, maybe supplement these with electric, mechanic and magnetic properties.
Candidate 12	The properties one measures depends on the working environment.
Candidate 13	You can identify areas of application for your molecule by "feeding" chemistry experts characteristics. These experts are only expert in their area of application.
Candidate 13	A possible "minimal set" of properties could be the data available on a technical data sheet (SDS, safety data sheet) used by a chemicals' supplier.
Candidate 16	There is (or could be) a difference between molecular and material characteristics.
Candidate 16	Start with determining structure.
Candidate 16	Subsequently, experts can be used to determine potential areas of application and from there you can measure properties that are important in the identified areas of application.

Table 14: Important statements from the second interview series about the framework translation.

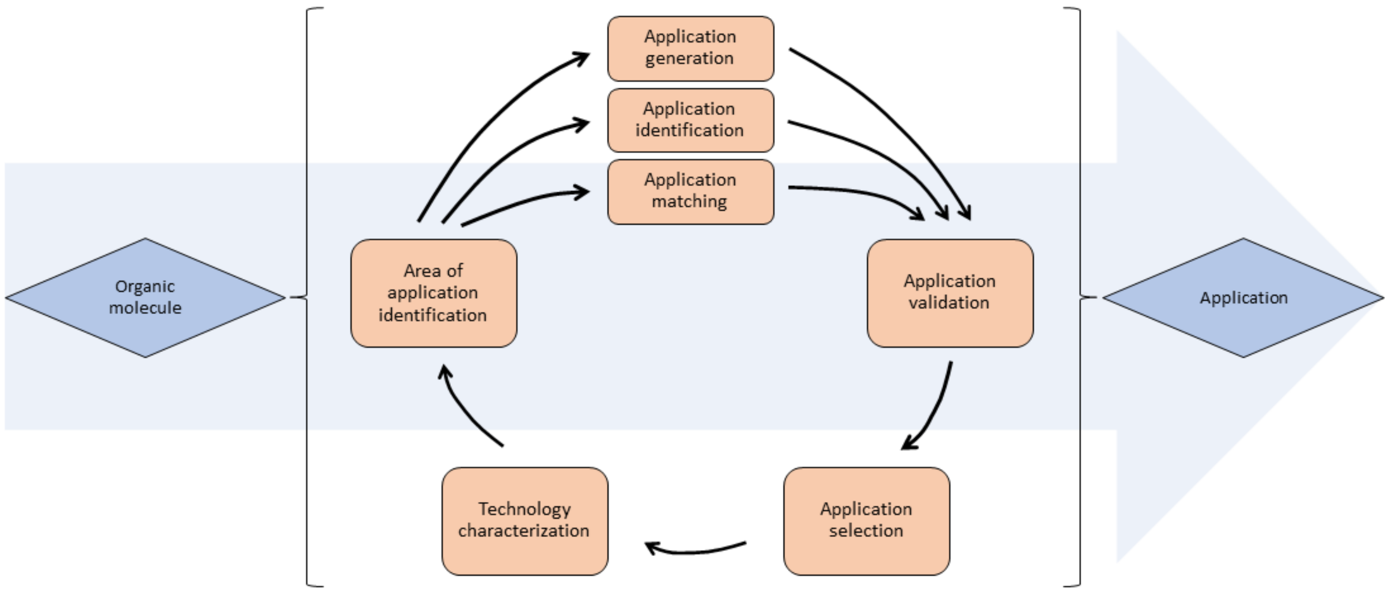

Figure 21: The developed and translated framework, version 1.

Some trends are visible throughout the interviews. For example, the important role assigned to “experts” in the identification of potential (areas of) application(s). However, I would like to find a way to minimize the role of experts, in the framework, especially minimize the number of phases in which experts have a role. By decreasing the involvement of experts, I hope to create a framework that can be used (almost) without dealing with the complicated nature of group time management.
I aim to find a way to capture the tacit knowledge the experts possess and make it explicit in the framework. A potential way to achieve this could be to list all possible areas of application for organic molecules and look at which properties of organic molecules are critical in these areas of application. Now by identifying properties of an organic molecule, the molecule can be linked to an area of application.
This approach was proposed *to* some of the interviewees (candidate 9, candidate 13 and candidate 16). They all thought this approach could (in theory) work. N.B. dr. ir. Meester proposed the same method, without me providing any suggestion in the direction of the method. He believes there should be literature available on this but does not know any examples.
Another common theme through some of the interviews is the identification of price as a quick selection method for molecules in a certain application. This is perceived as a good “quick and dirty” selection method, but it is unknown how and where this method will be implemented in the framework. This method could be featured in future research.
In the interview with candidate 9, the interviewee proposed a method to find areas of application by integrating two of the three methods proposed for molecular characterization. By creating a table like table 15, provided functional groups on one axis and characteristics/properties on the other, areas of application can be identified by connecting functional groups to measurable characteristics. An example of this is that a small alcohol (aka an alcohol with a low molecular weight) could potentially be used in a solvent application. Something that could make the proposed method difficult to implement could be the “black box” between molecular and material properties as stated by candidate 16.

In summary, three different methods for the identification of (areas of) application(s) have been discussed during the interview: presenting the molecule (structure) and its characteristics to experts, identifying critical properties for each area of application and cross referencing functional groups with molecular properties.

	Alcohol	Ester	Etc.
Molecular weight < X	Solvent	*Area of application*	*Area of application*
Unsaturated bonds	*Area of application*	*Area of application*	*Area of application*
Etc.	*Area of application*	*Area of application*	*Area of application*

Table 15: Area of application method proposed by candidate 9.

7.2 Translation

In this section, two methods will be proposed to translate the general framework developed in this thesis into a framework to generate or identify applications for organic molecules. The framework will not be completely translated, since it is believed this is an entire research project on its own. The method that will be presented in this section could be used as a flying start for a subsequent research project.
In the previous section, three potential methods for framework translation have been provided. The last two methods (identifying critical properties for each area of application and cross-referencing functional groups with molecular properties) will be described in more detail in this section. The method involving experts will not be discussed, since a goal at this point is the minimization of the role of experts in the framework.

7.2.1 Critical properties per area of application

The different steps needed to translate the framework using the "critical properties per area of application" approach have been summarized in figure 22.
In this section, a showcase will be presented in which some preliminary steps are taken in the method described in figure 22.

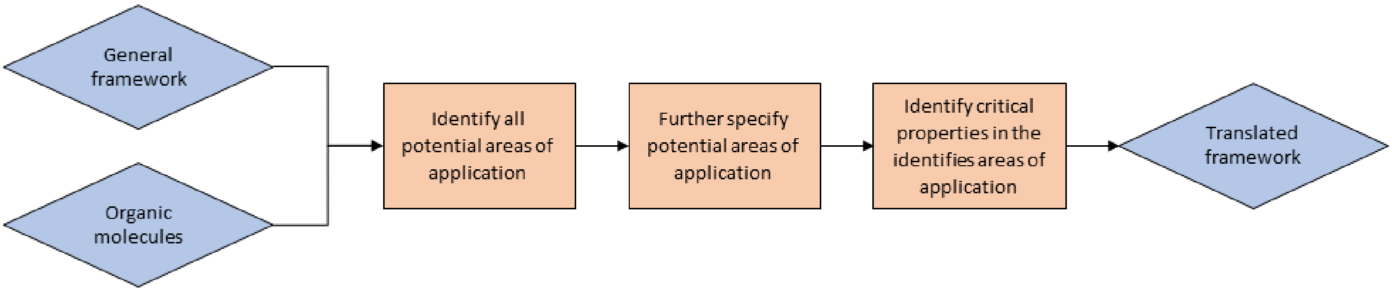

Figure 22: First proposed method for framework translation.

7.2.1.1 Identify potential areas of application

First, the potential areas of application for organic molecules will be considered. Following the video provided by the European chemical industry council [86], the chemical industry overall is active in the harnessing of energy, the purification of water, the conversion of waste into valuable resources, the enabling of mobility, nutrition, housing and health. ChemistryNL defines five themes in chemistry overall: climate, circularity, food, mobility and health [87].
The organic chemistry department of the American chemistry society (ACS) says: "Organic compounds are all around us […] in the rubber, plastics, fuel, pharmaceutical, cosmetics, detergent, coatings, dyestuff, and agrichemical industries, to name a few.

The very foundations of biochemistry, biotechnology, and medicine are built on organic compounds and their role in life processes. Many modern, high-tech materials are at least partially composed of organic compounds."

In a book by Benvenuto [88], the chapters give an overview of the raw material origin of the organic chemistry in industry: coal and (refined) (of which are separately discussed the C1, C2, C3, C4, C5-C8, [benzene, toluene, xylene], [naphthalene and higher polyaromatics], higher alkenes fraction, on top of that the other oils and lubricants). Moreover, the different areas of application for organic molecules are provided: Oils/lubricants, fuels, polymers, pharmaceuticals, food chemicals and food additives, agrochemicals.

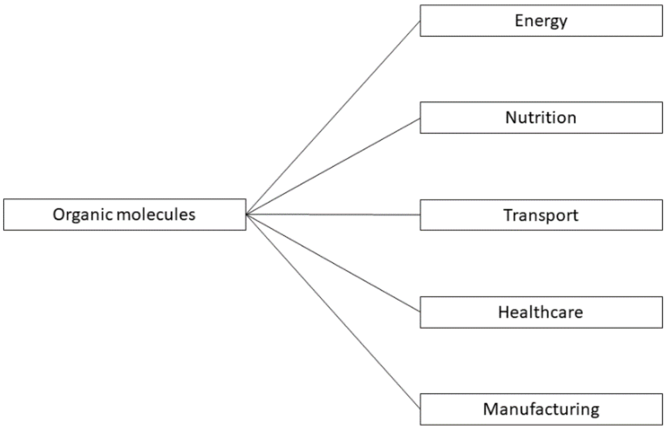

Figure 23: Macro level areas of application of organic molecules.

The different identified areas of application have been summarized in figure 23 as five macro level areas of application: energy, nutrition, transport, healthcare and manufacturing.
In the next step, the categories provided in figure 22 will have to be broken down further. This specification step is shown for "energy", since this area of application has already been identified as a potential area of application for the molecule from my first master thesis.

7.2.1.2 Further specify potential areas of application

In a paper by Hernandez-Burgos *et al.* [89], organic molecules are identified as promising material in cathodic applications, which can be extended to both cathodic and anodic.
From my own experience in the field of organic chemistry, I can obtain several search terms related to organic molecules in energy applications: organic molecules renewable energy applications, light harvesting organic molecules. With these search terms, the following areas of application were identified: organic photovoltaics, energy storage and energy transport. The potential areas of application have been summarized in figure 24.
In the next section, the molecule from my first master thesis will be considered, to see which properties of the molecule influenced the identification of potential applications in organic photovoltaics.

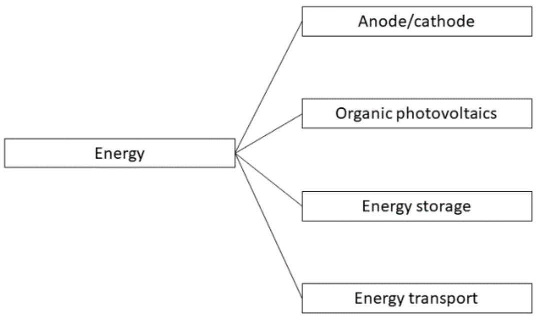

Figure 24: Area of application "energy" further specified.

7.2.1.3 Critical properties in the identified areas of application

In a paper by Dubey *et al*., several potential areas of application for perylene derivates have been identified: tuneable electron donor-acceptor systems, light harvesting arrays, photocatalysis, singlet exciton fission, organic photovoltaics, lasing, fluorescence probing and bio-labelling. All these areas of application could be fed back into the previous step.
The properties mentioned in the article are chemical robustness, photo and thermal stability, strong absorption and emission in the visible region, high electron affinities and high charge carrier mobility. How critical these properties are has to be assessed.

7.2.1.4 Concluding

In the previous sections, a showcase is provided for the translation method provided in figure 22. The first areas of application, with the first (critical) properties have been identified. The provided (macro level) areas of application and the subsequently identified critical properties are by no means exhaustive. They are meant to show the idea behind the translation method provided in figure 22 and it is believed they do.

In determining (macro level) areas of application, it was found to be difficult to identify every area of application on the same level. How necessary this is and how this could be done sensibly will have to be determined in subsequent research.

Lastly, although the framework presented in figure 22 is presented as a simple linear framework, it could be an iterative or even cyclic process. There might be more than two levels of areas of application, and the process of identifying these levels might be iterative.

7.2.2 Cross referencing

The different steps needed to translate the framework using the "cross referencing functional groups with molecular properties" approach have been summarized in figure 25.

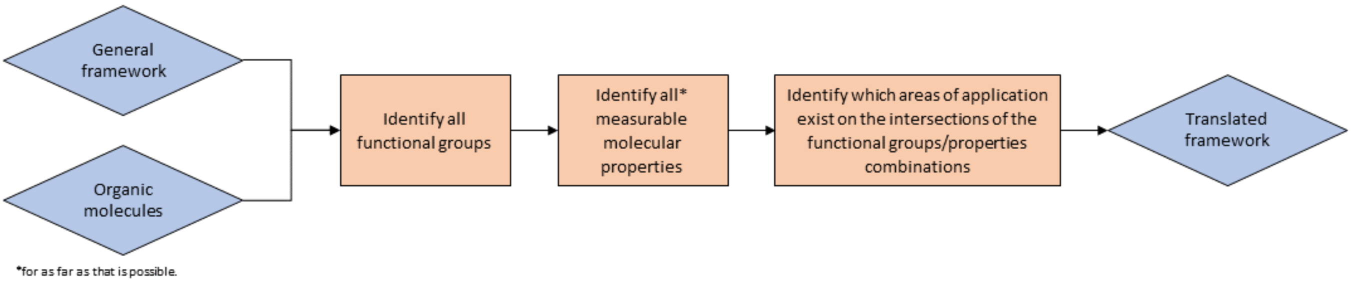

Figure 25: Second proposed method for framework translation.

Following the idea from candidate 9, to visualize this method, a matrix can be created, displaying the different types of functional groups on one axis, while displaying potential properties on the other axis. A mock-up of this matrix has been provided in table 15. In a subsequent research project, the matrix might be further completed (not in this project due to the potential elaborate nature of the matrix and the time limitation to this project). A starting point for the expansion of the matrix will be provided in this section, by identifying some functional groups and some measurable properties.

7.2.2.1 Functional groups and properties

From Brown and Poon [90] a first list of functional groups is gathered: haloalkanes, alcohols, esters, thiols, benzene derivates, amines, aldehydes, ketones, carboxylic acids, carbohydrates, lipids, amino acid and proteins.

There are several properties of organic molecules that can be identified. Some examples (from my own knowledge as a chemist and from the SDS format used by MERCK [91]) are: melting point, cooking point, molecular mass, aromaticity, phase at room temperature, colour, pH/pK_a and flash point.

Again borrowing from the knowledge on the molecule from my first master thesis, I would like to show the workings of the proposed method further. For example, considering the section of the matrix depicted in table 16, perylene can be considered as benzene derivates with a aromatic nature and a defined colour, which could indicate that they are a good fit for photovoltaic applications (that is, for *photo*voltaics, there needs to be a certain affinity towards light. Colour and aromaticity might indicate this fit). N.B. a perylene is actually a polycyclic aromatic compound, which does matter, since the size of the molecule (polycyclic vs single benzene) does matter in the absorption of light. This indicates that a better assessment of both the existing functional groups and the properties could improve the precision and accuracy of the method.

	…	Benzene derivate	…
…	…	…	…
Aromatic	…	*Organic photovoltaics*	…
Colour	…	*Organic photovoltaics*	…
…	…	…	…

Table 16: A showcase of the cross-referencing method.

7.2.2.2 More dimensions

The identification of either aromatic benzene derivates or coloured benzene derivates as potential photovoltaic materials is not wrong, but it is very crude. A potential improvement to this, apart from the previously discussed assessment of functional groups and properties, could be an increase in the dimensions of the matrix. By being able to include more properties and/or more functional groups, a more accurate prediction of potential areas of application could be provided. For example, in 3D, the in table 16 provided properties could both be connected to the same cell, providing that an aromatic and coloured benzene derivate could potentially be a good fit in a photovoltaic application. This prediction is expected to be more accurate than just an aromatic benzene derivate or coloured benzene derivate in a photovoltaic application.

7.2.2.3 Concluding

In the previous section, the workings of the translation method provided in figure 25 have been briefly demonstrated. As was already described in section 7.2.2.2, the demonstration was quite crude. As was mentioned before, the matrix represented in table 15 is only a section of the full matrix. On top of that, the number of dimensions that will be included in the final matrix has to be considered.

A last aspect of the proposed method that has not been discussed is the fact that the critical properties for the areas of application still have to be identified to be able to fill out the matrix. The two proposed methods might be more connected or even similar than originally perceived.

7.2.3 Combination

A potential useful combination of the two methods is provided in figure 26. The general idea is to use the matrix approach as a preliminary determination of a (macro level) area of application in which a molecule could find an application. A minimal set of properties and a reasonable amount of application areas should be presented in the matrix, to keep the matrix conveniently in use. By keeping the matrix relatively small, the development of the matrix should be less time intensive compared to the development of the matrix described in the previous section.

Once a first identification of an area of application has been done, the second method can be used to further divide the identified area of application into more specific areas of application. For the different areas of application identified in this phase, the critical properties have to be determined.

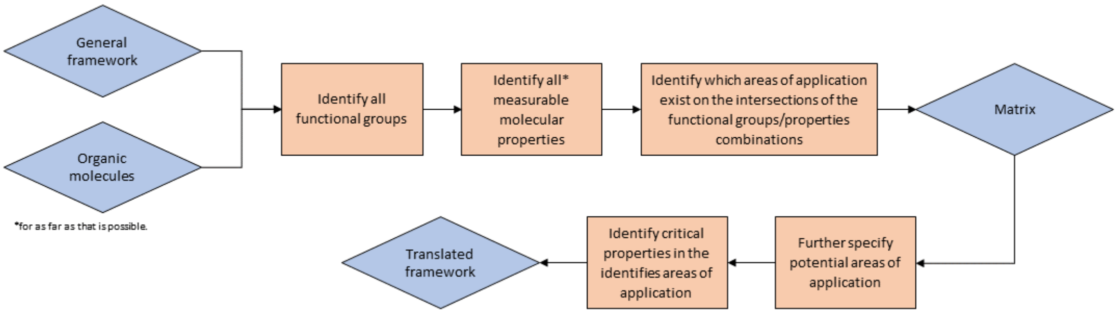

Figure 26: Combined method for framework translation.

The benefit of combining the two methods is twofold: the development time of the method is greatly reduced, since only part of the method has to be developed before it can be used and it is much easier to keep an overview of the entire method, compared to a full size matrix or a full size “decision tree” with areas of application.
A final improvement proposed for the methods (not only the combination, but all methods), is the inclusion of exclusion criteria. By being able to quickly discard certain areas of application based on exclusion criteria increases the amount of time and energy that can be given to other areas of application.

7.3 Concluding

In this chapter, three approaches to the translation of the general framework have been proposed. For the first two methods, a showcase has been presented in which the workings of the method have been briefly demonstrated. The chapter is intended to show the workings of the provided methods and identify some first challenges that might arise during the translation of the framework.

In the following chapter, a conclusion and discussion will be provided for this research. On top of that, suggestions for future research are provided.

8 Conclusion, discussion and future research

In this thesis, a framework has been developed to systematically generate or identify applications for a working principle. Literature on this subject is underdeveloped, up to the point where it is almost absent. The frameworks that do exist have been considered in the second literature review. From these frameworks, almost all frameworks treat the application generation or identification superficially, in line with the conclusion drawn by Strøm [1]. The framework created in this thesis provides a starting point for the proper treatment of the application generation or identification phase.

In this chapter, I would like to provide the reader a conclusion and discussion on the results of this research and some suggestions for future research. First, the SRQs and the RQ will be answered. Subsequently, the methodological issues and theoretical choices will be considered. Lastly, some recommendations for future research will be provided.

8.1 Final general framework

Through the figures 1, 11, 12, 19 and 20 the evolution of the general framework can be seen. Through the figures 4, 5, 6, 7, 8, 9, 13, 14, 15, 16, 17 the evolvement of the different identified phases can be seen. The final version of the general framework can be found below in figure 27. In this section, the essence of the framework is presented.

On top of that, this section presents two discussion points regarding the general framework: the starting point of the framework (technology vs scientific knowledge) and the inclusion of moderating variables.

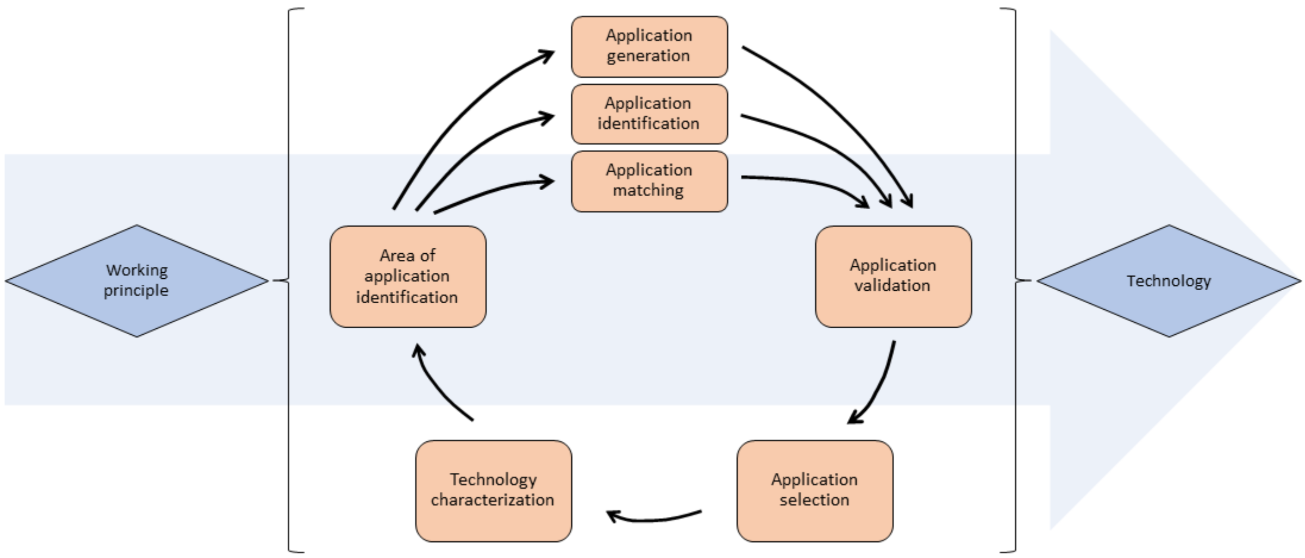

Figure 27: Final version of the general framework.

The framework in figure 27 is a framework that generates or identifies applications for a working principle. The framework is very general, which makes it broadly applicable, but less practically applicable. Two ways in which this framework can be useful are envisioned:

- The framework can be used as a rough guideline on what to do if you want to find applications for a working principle in any field.
- The framework can be used as a starting point for the creation of a framework that is applicable in a specific field.

The framework will be discussed from the outside in, starting with the starting and ending points:

- The starting point of the framework is “a working principle”. Originally, the idea was to develop a framework with “technology” as a starting point. However, considering the definition of “technology” provided in section 1.1 and the further exploration of the complex nature of the term “technology” during the expert discussion, a different starting point for the framework has been proposed in figure 27. The term “working principle” is the starting point for this framework, since it is (scientific) knowledge that could in theory be applied but does not have an implicit application.
- The ending point for the framework is “technology”. The ending point of the framework originally was “application”. However, again considering the definition of and discussion on the term “technology”, an application has already been incorporated in the term “technology”. The term “technology” is better suited as ending point of the framework than “application”, since “technology” provides more direction to the outcome. The outcome is not just an application, but an application embedded in a larger system that together is a technology.

Indicated by the blue arrow underneath the framework, the application generation of identification moves from starting point to ending point. The process by which this happens is proposed not to be linear, but circular:

- The circular shape of the framework was implemented after the expert discussion. However, it has been seen before the expert discussion, in the NCD framework from literature. On top of that, the notion that the user of the framework should go through (part of) the framework multiple times has been raised several times in the preliminary interviews and the second series of interviews. By considering the framework as a circular process where each phase is optional for each iteration of going through the framework, the phases of the framework can be best fitted to a specific situation in which the framework is applied.

Next, the five (seven) phases of that make up the circular part of the framework each have a specific role:

- The technology characterization phase is the phase in which relevant information on the working principle under consideration has to be gathered. The phase was previously called the information gathering phase. Following information from the frameworks from literature, the phase was renamed “technology characterization”. Apart from information gathering, characterization takes into account which information to gather and how to display this information.
- The area of application identification phase was originally added to the framework after the preliminary interviews. The idea that the identification of an area of application might be part of the application generation or identification process is backed by the frameworks from literature. No explicit objections to this phase were found during the validation steps performed during this thesis.
- The application generation, application identification or application matching phases are three separate phases in the framework that have the same goal: obtain potential applications. How these potential applications are obtained is different for each of the phases. The difference between generation and identification has been present throughout most of this thesis. The application matching was added following the preliminary interviews.
- The application validation phase was previously called the application development phase. The name was changed following the second interview series. During these interviews, the term “development” led to confusion on how extensive this phase is. The term “validation” better demonstrates the notion that this phase is about showing that the envisioned application works for the “working principle” that is under consideration.
- The application selection phase has been present in the framework throughout the entire development. In the linear representation of the framework, the selection phase has changed places with the application validation, but in the final (circular) version of the framework, this is no longer relevant.

8.1.1 Framework characterization

In section 5.7, a characterization of the frameworks from literature was presented. The characteristics for the framework created in this thesis will be presented in this section.
In this thesis, a circular framework was created that takes a problem solving focus, as opposed to a customer focus. On top of that, it is a framework that focusses on generating or identifying applications that have a high impact/relevance.
The selection method employed in this framework has not been specified yet. However, it has been stated that a quantitative selection method is desirable.
Lastly, the framework created in this thesis explicitly treats (and maybe even focusses on) the application generation or identification phase. As was mentioned at the beginning of this chapter, the created framework provides a good starting point for further consideration of this phase. As will be discussed in the future research section, a future research project is needed to capture the full picture on the application generation or identification phase.

8.1.2 Moderating variables

In figure 1, the envisioned output for this research was provided. In this framework, moderating variables are mentioned between the different phases. No specific attention was given to the moderating variables in this research, but it is still believed moderating variables exist and are important.
A first example of a moderating variable that effects the entire framework is provided in the NCD framework: the organizational climate.
A moderating variable specifically for step from area of application towards application generation/identification/matching could be domain knowledge. Domain knowledge could limit one's openness to innovation. However, later, the domain knowledge could be used as an advantage in the validation or selection phases.
Only a few moderating variables have been identified in this section. Other moderating variables probably exist and should be identified to further complete the framework developed in this research.

8.2 Answer to the research questions

In this section, I would like to answer the research questions that were posed in chapter 1. I will answer the SRQs first, before answering the main RQ.

1. Can a framework to systematically search for applications for technology be developed?

This research has shown that this is possible, although some nuance has to be introduced into the question.
Firstly, during the expert discussion, it was proposed that "applications for technology" is somewhat impossible, since technology by definition already has an application. So rather, the questions should be "can a framework to systematically search for the applications for a working principle be developed?"
Secondly, systematicity is something that has not been extensively treated in this thesis. It is believed the framework that has been developed is systematic, following the provided definition and explanation of "systematic" in chapter 1.

2. How can such a framework be translated to a framework for organic molecules?

Before the question "how can the framework be translated", first the question "can the framework be translated" has to be answered. The answer to this last question is believed to be "yes", with the proof provided in the showcases of chapter six. However, more research is needed to give a definitive answer.

This is also the answer to the "how" question: it is believed the framework can be translated by using one of the methods provided in chapter six, but more research is needed to confirm this answer (and to actually show that the framework can be translated).

3. How can this/these framework(s) be validated?

The general framework developed in this research project has been partly validated, through interviews and discussion with experts in the areas of (organic) chemistry, valorisation management, innovation management and innovation.

However, it is believed that to increase the validation potential of the framework, the specificity has to increase. The more general the framework is, the easier it is to label the framework as "right", but also the less usable the framework is. By increasing specificity, introducing more concrete methods and data sources into the framework, the framework becomes more testable through usage and cases.

Now the main RQ:

Can a framework be developed to systematically search for applications for organic molecules?

It is still believed that this is possible. However, this research only hints at the possibility and does not prove it. Considering the answer to the first sub research question, a framework to find applications for scientific knowledge has been developed. Taking into account to answer to the second sub research question, it is believed the provided translation methods could be used to translate the general framework into a framework that systematically generates or identifies applications for organic molecules.

8.3 Methodological issues and theoretical choices reconsidered

Throughout this thesis, a learning effect has been experienced when considering the vocabulary that has been used and the relative importance of several definitions. Being relatively green on the subject of finding applications for technology, a considerable amount of struggle through this thesis was about finding the right vocabulary needed. To give an example, the literature study was a challenge, since a lot of articles have words like "technology" and "application" either in the title or in the text. Although these articles have the words "technology" and "application" in the title or text, they do not talk about how technology finds applications. However, using terms like "the front end of innovation" or "the fuzzy front end" might yield much quicker results when searching for literature on how scientific knowledge find its application.

Apart from vocabulary, the perceived importance of definitions (mostly the ones provided in chapter one) has increased during the duration of the research. Terms like "technology" or "application" are used very often in an environment around a technical university. This gives someone the notion that these terms are known, but it turns out defining these terms properly is not something trivial.

In the first literature study, it was found that a literature on application generation or identification for technology/a working principle was scarce. To overcome this obstacle, a design approach was taken in this research. I had no prior knowledge of design methodologies, but the used approach can be classified in hindsight. Consulting the Delft design guide by Boeijen *et al.* [16], it can be seen that several models, approaches and perspectives on design exist. Although the provided list might not be exclusive, it is a good starting point.

Considering the models, approaches and perspectives in the Delft design guide, the approach followed in this research closely resembles the basic design cycle. A short description of this methodology is provided in appendix K. The similarity between the proposed design process and the process used in this thesis is reasonable. A aspect that is not used in this thesis is design criteria. Using these might have improved the design process, since the design criteria force one to clearly think about the goal of the design beforehand.

During this thesis, understanding the goal of the design was something that happened during the process of designing, but without specific (enough) attention.
Lastly, the target audience should have been a more integral part of my research. It is believed that by clearly defining a target audience for a framework, the design of the framework could have been done within the context of this target audience. It is believed that this might have increased the practical applicability of the framework, or decreased the vagueness.

8.4 Future research

At several points throughout this thesis it has been identified that subsequent research is needed in many aspects considered in this research. Four of the aspects that are most important are considered in this section.

Firstly, the general framework developed in this research (of which the most recent version has been depicted in figure 27) could be further developed. Most importantly, the application generation or identification should be further explored, for example by an in-depth consideration of creativity methods. A starting point in literature has already been provided ([68]).

Secondly, a more systematic and complete literature study should be conducted. No illusions about the completeness of the current literature study exist. A literature study by R. Strøm exists (same author as the master thesis referenced throughout this thesis [1]). However, this literature study is not publicly available. The document has been requested at the NTNU (the Norwegian university of science and technology), but no document has been received yet.
A more complete literature study might either be used in proving (or disproving) the synthesized framework, or conclude that no highly comparable framework exists, thus making the need for this research more evident.

Thirdly, the translatability of the framework has been shown, but only preliminary. The methods to translate the general framework into a framework that can be used to identify applications for organic molecules should be further refined or redefined and possibly expanded. Their workings should be shown and tested, more so than was done in this thesis. On top of that, completely different methods for the translation of the framework into a framework for application identification for organic molecules might exist.
In addition, it is believed that by identifying the right methods and formulating the right goals, the general framework can be translated into almost any type of application finding framework (as long as it has something to do with a working principle of knowledge). In future research, a framework to translate the framework could be created, with which people can identify the right information and methods to translate a further developed general framework into a framework for their specific wants and needs.

Finally, a more fundamental, philosophical or etymological research project could be set up to identify some of the concepts used throughout this research project. For example, finding a scientific and unambiguous definition for technology was found to be challenging during this research project. Properly defining some of the terms used in this research will likely improve the clarity and with that, probably the practical applicability of the final framework.

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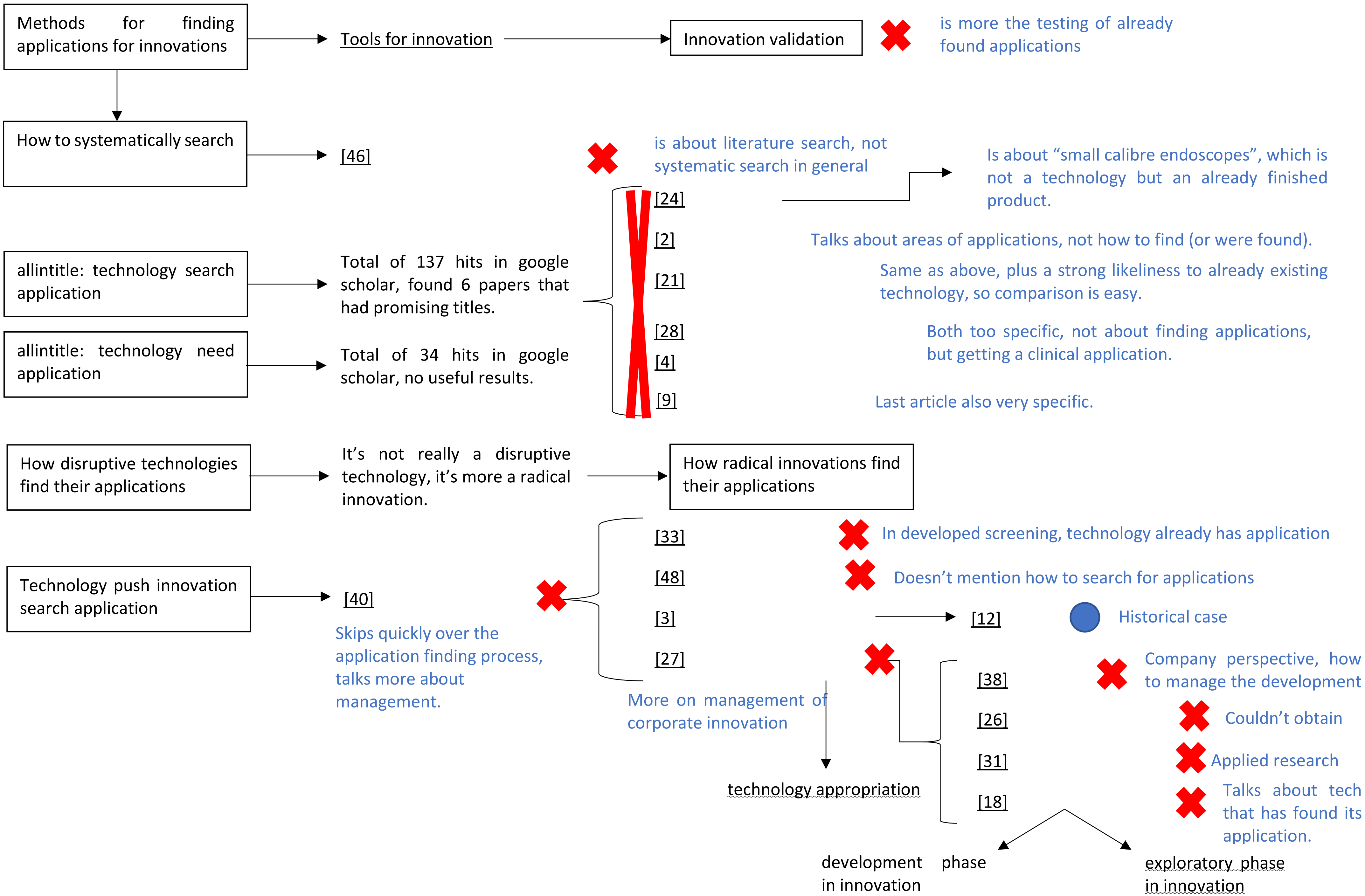
Appendix A – Literature study

In this appendix, I want to show the process of my first literature study. Here is how to read it:

Each textbox with a line around it represents a search term.
Each bit of underlined text represents a piece of literature (paper, book, etc.)
Each ✖ represents a dead end.
Each piece of blue text represents an explanation (for example, an explanation of why a certain end is a dead end).
Each piece of curly underlined text represents a possibly useful search term.
Each ✚ represents a high potential article.
Each ● represents an article I should read or read later.
Each ▲ represents an article that has been read and was (somewhat) useful.


Methods for finding applications for innovations
Tools for innovation
Innovation validation
is more the testing of already found applications
How to systematically search
[46]
is about literature search, not systematic search in general
[24]
Is about "small calibre endoscopes", which is not a technology but an already finished product.
[2]
Talks about areas of applications, not how to find (or were found).
allintitle: technology search application
Total of 137 hits in google scholar, found 6 papers that had promising titles.
[21]
Same as above, plus a strong likeliness to already existing technology, so comparison is easy.
[28]
Both too specific, not about finding applications, but getting a clinical application.
allintitle: technology need application
Total of 34 hits in google scholar, no useful results.
[4]
[9]
Last article also very specific.
How disruptive technologies find their applications
It's not really a disruptive technology, it's more a radical innovation.
How radical innovations find their applications
[33]
In developed screening, technology already has application
[48]
Doesn't mention how to search for applications
Technology push innovation search application
[40]
[3]
[12]
Historical case
Skips quickly over the application finding process, talks more about management.
[27]
[38]
Company perspective, how to manage the development
More on management of corporate innovation
[26]
Couldn't obtain
[31]
Applied research
technology appropriation
[18]
Talks about tech that has found its application.
development phase in innovation
exploratory phase in innovation

Search for work by:
E. Karana
B. Barati
B. Petreca
(Names from interview with Sylvia)

→ ✖ Work on material experiences, which is not quite close enough to my subject to be useful.

3 articles from a fellow student (after briefly talking about my subject):

[36] ✖ Is about spin-out companies, in a stage where the application for a technology has already been found.

[34] ✖ Article is about entrepreneurial competencies, not about anything “finding applications” related.

[30]

- [11] ✖ Is about spin-out companies, in a stage where the application for a technology has already been found.
- [25] ✖ Is about spin-out companies, in a stage where the application for a technology has already been found.
- [19] ✖ Is about spin-out companies, in a stage where the application for a technology has already been found.
- [10] ✖ Is about spin-out companies, in a stage where the application for a technology has already been found.
- [5] ✖ Is about spin-out companies, in a stage where the application for a technology has already been found.
- [37] ✖ Is about spin-out companies, in a stage where the application for a technology has already been found.

sources of innovation

spin-out companies

allintitle: technology push application (looked through first 3 pages).

→ [14]

Technology-push lead user concept, about users finding applications

→ “referenced by”

- [45] ✚
- [1] ✚
- [7] ✚ ▲
- [8] ✚ ▲

[20] for historical cases

- [29] On how customers create applications for a new technology.
- [35] Probe and learn process.
- [44] ✚
- [17]

[15]

[13]

[42] On how discovering opportunities is gathering information and searching.

[39] Identifying market opportunity.

Re-reading the paper by [40], to determine usefulness.

[41] Is about methods to introduce innovative products to the market, a stage further finding applications.

[22] Writes from a "problem to solve" perspective.

[7]

[49] Studies 11 radical innovations, establishes the importance of vision.

[32]

[6]

...

...

...

...

[8] → "referenced by"

Mentions the importance of creativity, includes model for FEI

[1] → [23] → [43]

FEI, or front end innovation, might be useful search term.

On exaptation, also mentions serendipity.

Appendix B – emails to candidates

B.1 Preliminary - email beforehand, English

Subject: Interview for my master thesis

Dear …,

Would it not be great if we would have a method to come up with applications for a totally new invention. That there would be a framework that systematically takes us through several steps that yield a list of possible applications? I aim to develop this method or framework in this thesis and I would like to ask for your help.

More specifically, I aim to develop a framework to systematically search for applications for organic molecules. I choose “organic molecules” as a unit of analysis to honour my background in chemical engineering.
As a base for the framework, I first want to make an inventory of the different ways available to do systematic search for applications for different units of analysis. That is to say, I want to make the initial scope broader than just “organic molecules” (although one might argue that “organic molecules” is already quite a broad scope).
I want to make this inventory by doing several interviews with experts, and I think you are one of these experts.

The interview will take roughly and hour. It would be a great help to me if you could make the time to participate in this interview. As preparation for the interview, you could (but of course don’t have to) try and think of ways that you know to find applications for “something new”. This “something new” might be a bit vague, but it is used on purpose, to indicate you do not have to limit yourself to the scope of this research. If you don’t know how to find applications for organic molecules but know very well how to find applications for new materials (just an example), it would help me to know how you would approach this.

I believe you would be a good candidate for this interview, because [reason why this person is a candidate for the interview].

Looking forward to hearing from you if you would like to participate. If so, let us find a suitable date and time to meet.

Sincerely,

Jesse van Mullem
Master student management of technology at the Delft university of technology.

B.2 Preliminary - email beforehand, Dutch

Onderwerp: Interview voor mijn master thesis

Beste …,

Zou het niet geweldig zijn als we een methode zouden hebben om toepassingen te vinden voor een compleet nieuwe uitvinding? Dat er een raamwerk zou zijn dat ons op systematische wijze meeneemt door een aantal stappen die leiden tot een lijst opleveren met mogelijke toepassingen? Ik heb als doel dit raamwerk te ontwikkelen in mijn *master thesis* en daar heb ik uw hulp bij nodig.

Om preciezer te zijn, mijn doel is een raamwerk ontwikkelen om op systematische wijze te zoeken naar toepassingen voor organische moleculen. Ik heb "organische moleculen" gekozen als mijn analyse-eenheid als knipoog naar mijn achtergrond in *chemical engineering*.

Als basis voor het raamwerk wil ik een inventarisatie maken van de verschillende manieren om systematisch te zoeken naar toepassingen voor verschillende analyse-eenheden. Dat wil zeggen, ik wil in eerste instantie een breder blikveld nemen dan alleen "organische moleculen" (echter zou men ook kunnen zeggen dat "organische moleculen" op zich al een erg bredere analyse eenheid is).
Deze inventarisatie wil ik maken door interviews af te nemen bij experts en ik denk dat u één van deze experts bent.

Het interview zal ongeveer een uur duren. Het zou mij enorm helpen als u de tijd zou kunnen maken om mee te doen aan dit interview. Als voorbereiding voor het interview zou u (alhoewel dit zeker niet hoeft) alvast na kunnen denken over manieren om naar toepassingen voor "iets nieuws" te zoeken. Dit "iets nieuws" is wellicht wat vaag, maar dit is bewust vaag gehouden, om aan te geven dat u uw denkproces niet hoeft te beperken tot de analyse-eenheid van mijn onderzoek. Als u geen idee heeft hoe u zou kunnen zoeken naar toepassingen voor organische moleculen, maar wel een idee heeft hoe u zou zoeken naar toepassingen voor nieuwe materialen (slechts een voorbeeld), dan zou het mij helpen om te weten hoe u dat aan zou pakken.

Ik denk dat u een goede kandidaat voor dit interview zou zijn, omdat [reden waarom deze persoon een goede kandidaat voor dit interview zou zijn].

Ik hoor graag van u of u bereid bent deel te nemen aan dit interview. Mocht dat zo zijn, laten we dan kijken wat een goede datum en tijd zou zijn om elkaar te ontmoeten.

Met vriendelijke groet,

Jesse van Mullem
Master student *management of technology* aan de TU Delft.

B.3 Preliminary - email afterwards, English

Subject: Summary interview

Dear …,

Thank you again for participating in the interview.

In this email, I would like to summarize our conversation. If you find anything that you want to alter, remove or add, please let me know.

[summary]

On top of the summary, during our interview you indicated that you do/don’t want to be approached again in a later stage of this research project. [stand by this choice?]

Sincerely,

Jesse van Mullem

B.4 Preliminary - email afterwards, Dutch

Onderwerp: Samenvatting interview

Beste …,

Nogmaals hartelijk dank voor uw deelname aan het interview.

In deze mail zou ik graag ons gesprek samenvatten. Mocht u iets tegenkomen dat u aan zou willen passen, eruit willen halen of toe zou willen voegen, dan kan u mij dat laten weten.

[samenvatting]

Tot slot, tijdens het interview gaf u aan dat u in een later stadium van mijn onderzoek wel/niet nog een keer benaderd zou willen worden. Bent u het nog steeds eens met deze keuze?

Met vriendelijke groet,

Jesse van Mullem

B.5 Second - email beforehand, Dutch

Onderwerp: Tweede interview

Beste …,

Enige tijd terug hebben wij een interview gehad voor mijn master thesis. Ik had toen gevraagd of ik u eventueel nog een keer zou mogen benaderen. Ik zou u bij dezen graag willen vragen of u nog een keer een interview/gesprek met mij wil houden. Heeft u de komende 2 weken wellicht tijd voor een interview? Excuses dat het zo kort dag is. Ik verwacht dat het interview tussen een half uur en een uur duurt.

Ik heb inmiddels een raamwerk gemaakt om toepassingen voor technologieën te vinden en dit raamwerk vergeleken met relevante literatuur.

Ik zou in ons gesprek graag van u horen wat u van het raamwerk vindt en ik zou samen met u willen kijken of we de vertaalslag naar de chemie kunnen maken (het raamwerk door ontwikkelen tot een raamwerk dat mogelijk toepassingen voor organische moleculen kan vinden).

Ik hoor graag van u.

Met vriendelijke groet,

Jesse van Mullem

B.6 Second – email afterwards, Dutch

Onderwerp: Samenvatting interview

Beste …,

Nogmaals hartelijk dank voor uw deelname aan het interview.

In deze mail zou ik graag ons gesprek samenvatten. Mocht u iets tegenkomen dat u aan zou willen passen, eruit willen halen of toe zou willen voegen, dan kan u mij dat laten weten.

Met vriendelijke groet,

Jesse van Mullem

Appendix C – Candidate selection

In this appendix, the candidates selected for the interviews and discussion are presented. Each candidate has a short description. The appendix has two sections, one for the scientist candidates and one for the industry candidates.

C.1 Scientist candidates

Ten different scientists will be interviewed in the preliminary interviews. N.B. the first three candidates are not really scientist, but rather current/former students of the Delft university that I know to be innovative thinkers (or that are recommended by students that I know).

- Candidate 1.: a master student computer science at the Delft university, with a bachelor's degree in industrial design. This interview was supposed to be a pilot interview, but the subsequent framework obtained from this interview looked as a promising result, so a decision was made to include the framework in this thesis. The interviewee does not have any professional experience in finding applications for technology. However, she is a (self proclaimed) creative person and creativity is believed to be an important aspect of the framework the developed framework.
- Candidate 2: a former student of the Delft university with a master's degree in industrial design (design for interaction). She currently works a professional visual thinker, for example by making minutes at meeting through drawings. She has been recommended by candidate 1. as a candidate for the interview. Her area of expertise is, personally and professionally, more in the area of creativity than in the area of application generation or identification. However, as indicated before, it is expected creativity will have an important role in the framework.
- Candidate 3: again a former student of the Delft university with a master's degree in mechanical engineering (biomechanical engineering) and a bachelor's degree in industrial design. She currently works as a business consultant at First Consultant, but during her previous work experience obtained some experience with leading creativity sessions. She has been recommended by candidate 2 as a candidate for the interview. Again, this candidate is more experienced in creativity than in application generation or identification.
- Candidate 4: a full professor at the Delft university, his research focusses on developing a theoretical framework that represents the field of technological innovation. Apart from his research career, he also has experience as a (innovation) management consultant. His experience in finding applications for technology comes both from his academic and his industry career. As a management consultant he advised on product development processes. His research interest is in the field of innovation and technology development.
- Candidate 5: a full professor at the Delft university, her areas of expertise are reported as strategic innovation, fuzzy front end and innovation tools. Apart from her academic career, she has ample experience in industry as new product developer, business development manager, product manager and consultant. She is founder and managing director of Sunidee, a strategic innovation agency, specialized in the fuzzy front end of innovation. She was recommended by dr. Van der Bijl-Brouwer as a candidate for the interview. Her experience with Sunidee is very relevant for this research, since the application identification or generation is part of this "fuzzy front end" of innovation (see for example Koen *et al.* [75]).
- Candidate 6: an assistant professor at the Delft university, his research focusses on waste management and circular economy.

Apart from his research experience, he has working experience as a project manager and a business engineer. He was recommended by prof. dr. ir. De Haan as a candidate for the interview. He was recommended by prof. dr. ir. De Haan for his experience in waste management, where he faced the challenge of finding applications for waste streams several times.

- Candidate 7: an associate professor at the Delft university, with a research interest in product design. Apart from his academic career, candidate 7 has experience as a senior scientist, developing new products for the food and pharma markets. This is also where his experience in the identification of applications comes from, although it is unclear how vast this experience is.
- Candidate 8: an associate professor at the Delft university, his research focusses on innovation and entrepreneurship. He was recommended by candidate 4 as a candidate for the interview. He was recommended by candidate 4 because he has been teaching a course called "turning technology into business" for several years, where groups of students analyze business potential of patents. For this course, candidate 8 developed his own method to identify potential applications from patents. This method has been presented in a paper that he wrote himself [92].
- Candidate 9: a full professor at the Delft university, with a vast experience in the field of polymer chemistry. He was recommended by candidate 7 as a candidate for the interview. He is recognized by candidate 7 as someone who has a special skill in creative problem solving and in translating a demand into a molecular structure. His experience in application identification comes from his career as a scientist, for example illustrated by the example about wastewater molecules that was mentioned in the preliminary interview with candidate 7.
- Candidate 10: an assistant professor at the Delft university, her research interest are smart materials and shape morphing design. Although her research and experience are not directly in the field of application identification, she is still part of the design engineering department, which might give her an idea of how to approach the application generation or identification. On top of that, her background is in mechanical engineering, which might provide a different look on the subject, compared to the scientist from industrial design who have an industrial design background.

C.2 Industry candidates

The selection of the industry experts has also been described in appendix B. Four different experts from industry will be interviewed in the preliminary interviews:

- Candidate 11: a former student of the Delft university, with a master's degree in chemical engineering. Has several years of experience as product development manager, innovation director, technology director and CTO at DSM, Pentair and Aliancys. He was recommended by prof. dr. ir. De Haan as a candidate for the interview. As product development manager and innovation director, it is believed candidate 11 has experience in the application identification or generation process.
- Candidate 12: a former student of the Fontys university of applied sciences, where she obtained a degree in chemistry and former PhD candidate of the university of Twente, where she obtained a PhD in polymers and biomaterials. She has experience as program manager, new business development manager, segment leader and project manager at DSM, Dunlop protective footwear and polymer science park. She was recommended by prof. dr. ir. De Haan as a candidate for the interview. Her experience in application identification comes mainly from her time as a PhD candidate, when she worked together with a research partner to develop a scaffold application for the polymer she was researching.
- Candidate 13: a former student of the Twente university, where he obtained a master's degree in chemical engineering. He has experience as R&D director, director sustainability and business development, director science to innovate, manager research and development, and senior business developer at DSM, Bolsius group and TNO.

Comparable to candidate 11, it is expected that candidate 13 as a former director science to innovate, manager research and development and senior business developer has experience in the application generation or identification process.

- Candidate 14: a former student of the Erasmus university in Rotterdam, where he obtained a master's degree in business administration. He has experience as a business consultant, but more importantly, experience as business relations manager at the valorization (technology transfer) office of the Delft university. He was recommended by a contact at the valorization office as a good candidate for the interview.

Appendix D – Interview reports

N.B. Every interview was recorded. Before each interview, the respondents will be asked if they consent to me recording the interview (as an audio file for face-to-face interviews, or as a video file for skype interviews). This recording will be treated highly confidential, with the files remaining on the recording device and/or the google drive I am using during this thesis. On top of that, only I and if necessary, my direct supervisor (dr. J.R. Ortt) will get to listen to these interviews.

D.1 Interview M. Visser, bacc. (candidate 1)

N.B. the interview was held in Dutch and thus has been translated. On top of that, this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

Have you ever had to search for applications for something new?

Yes, once I got a tree from a park nearby and another tree from our own garden. One of these trees I made into a set of supports for the windowsill, another tree I made into a coat rack.

Any idea how you at the time approached finding applications for the two trees you had lying around?

Yes, for the first tree (the one made into supports), I saw my windowsill bending and wanted to fix this (**reasoning from a problem towards a solution**).
On top of that, looking on the internet, one can find that using natural materials in your house is somewhat of a trend. I can also see this at my neighbours' and/or at my friend's place. These are good places to find inspiration (or even to copycat from) (**following trends, finding inspiration, copycatting)**.
Now you have a trend + a problem I want to solve. Now having the trees lying around, the link is quickly made to use the trees as solution to my problem.

How could we pose this as a more general theory? Would it suffice to say you have a certain problem you want to fix and the material in close vicinity poses an easy solution to the problem?

Partly, but on top of that I always have a list of things in my mind I still want to do at some point and when the right "thing" (material) presents itself, it is easy to do one of these things. When I find something, I always start to think "what can I do/make with this?".

Can you think of other ways to find applications for something new?

It is difficult to do this without an example, can you give me an example?

Well, an easy example for me would be an organic molecule, but since you have no background in chemistry, this might not be a useful example to you.

No, not really, I would not know how to do something with an organic molecule. This raises the importance of the area of application and a person's experience in the area of application. For example, in code software, when you have some experience you know what is possible and what is not, same goes for woodworking.
More specific for woodworking is also the limitation of which tools you have available.

There is another thing where I walk on the street and see things where I randomly think about how to improve these things, or extent. In this, sometimes, there is also a component involved of wanting to "impose" (to strong of a word, replace with a better fit) your ideals onto society.
Apart from that, sometimes you just randomly find solutions for certain problems, by **trial and error**.

However, this "improving" is a step you can only take when you already have an application.

Fair enough.

Now let me add some methods to the methods we already have: consulting experts, searching literature, exploiting properties.

Apart from experts, you can always “**crowdsource your peers**”.

How would you go about comparing these methods? Which criteria would you use?

A good start could be to divide them between passive and active methods. This is not a judgement of value, I think both passive and active methods are needed and that they exist next to each other.
Another way I would rank these methods is from easier to less easy. Or based on whether I would use them or not (although I find I rank the methods I came up with as “useable” and the methods you added to that as “non-useable”).
Another way I would rank these methods is based on the amount of commitment you need to have in your idea, or how much you are already invested in an idea. For example, **brainstorming** is a very accessible method, while consulting an expert requires more investment in your idea.

How would you make a framework out of the methods we have so far?

I would do the methods where you have to think freely (for example the brainstorm) before grabbing a certain source of inspiration (like a computer).
Trial and error is something I would do after the brainstorm, but you need to brainstorm about what you want to trial and error.

Brainstorm should not involve any selection. Thus, when you do arrive at the selection phase, you should first remove the ideas that are absurd and/or not feasible at all.
For the ideas that are left, you could consult an expert to ask his/her opinion on the ideas or do a literature study to see if something has been done already/someone has done something that you can build upon.

Is building upon something really selection?

It could be; it can be easier to work on an idea that can, in some way, build upon something else. However, it might not be the best selection criterium, since the ideas that build upon something else might not be the most interesting.
An important question to ask yourself here is what you want to achieve with the new idea, “how big do you want to make it.” Available resources also play a role.
This might also be generalized as saying it might be good to set up a couple of selection criteria and rate the different ideas on each of these criteria, giving each idea a final score.
After selection, you should end up with a couple of ideas (let’s say 4). You should invest some time and resources in all these ideas and set yourself a deadline to choose one of these ideas. This choice could be connected again to a set of selection criteria.
To make this work, your framework should be rigid, but the different tasks should be flexible (for example, in time).
Maybe an idea to literally ask the interviewee to come up with a framework with the methods developed during the interview?

May I approach you again in a later stage of the research? (to test the framework)

Yes

Are there any people that I should do the interview with?

Do this interview with Sylvia Machgeels, since what we are doing here is pretty much her job. Also, do this interview with Arie van Ziel.

Is there any literature you can recommend I read following the content of this interview?

Yes, a book on behavioural change support systems, [93].

D.2 Interview ir. S.M.C. Machgeels van Ziel (candidate 2)

N.B. the interview was held in Dutch and thus has been translated. On top of that, this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

Have you ever had to search for applications for something new?

There are a lot of design methods, each with several phases. The method we learned has 3 phases: question (problem), ideas and implementation. Every phase has a divergent phase, where ideas are generated, and a convergent phase, where ideas are selected. For each phase, and for both converging and diverging in these phases, there are different methods available.

Alright, you paint a nice overview. However, we quickly go into "how to design", as opposed to how to find applications. Let's return to the first question, have you ever had to search for applications for something new?

Well, I've never done a project exactly like that. However, my thesis supervisor developed a toolkit to find applications for new materials. This toolkit is called material driven design. However, this toolkit is still under development and can't be shared at this point in time.
Elvin Karana is developing this toolkit.
Download her PhD, and also articles she published.
The toolkit consists of 4 subjects, with different questions to make the user think about these subjects. The 4 subjects are understanding, vision, patterns and design. The method goes from a "factual" to a "visionary" approach, back to "factual" and again to "visionary" (understanding and patterns are factual in the sense that it describes the "real" properties of the material, vision and design are visionary).

Lets for now get rid of the framework. If feel if we keep it on the table now, we will end up recreating the framework in our own words through answering my questions.
So, now that we got rid of the framework: say I gave you a new material, how would you approach finding an application for it?

I would analyse the material, I would touch/feel and interact with it. I would collect facts about the material through measurements, I would describe how I feel about the material and I would describe how the interaction with the material was.
In the next step I would attach advantages and disadvantages to the different aspects of the material. I would think about how to turn disadvantages into advantages. I would also do this phase with a group. The next step for me would be to come up with ideas about what to do with the material. I would also do this phase with a group.

I would also select some of the ideas generated and look at the materials that are already used in these applications, to find out whether my new material could do better in these applications. On top of that, I would also look for "gap in the market" applications for the material based on the generated ideas.

The last phase in this cycle would be testing the (several) application(s) via prototyping and letting people interact with these prototypes.

Any literature that you would recommend I read about this subject?

- Game storming by Gray Brown Macanufo (mostly about design science, but this could for example be useful in designing your framework)
- Booming bamboo by Pablo van der Lugt (book about how they found applications from bamboo. The method might be extracted).
- Sylvia's thesis
- Maybe the article: Karana, E., Barati, B., Rognoli, V., & Zeeuw Van Der Laan, A. (2015). Material driven design (MDD): A method to design for material experiences.

May I approach you again in a later stage of my research?

Yes

Is there anyone you can think of that I should interview too?

Yes, Mirte Freriks. In the beginning of her master thesis, she did exactly what you describe: she had a material and was looking for an application for that material.
And if they have time, Elvin Karana (professor supervising the toolkit project), Bahareh Barati and Bruna Petreca (two PhD she worked with during the toolkit project).

D.3 Interview ir. M. Freriks (candidate 3)

N.B. the interview was held in Dutch and thus has been translated. On top of that, this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

Do you have any experience with looking for applications of new technologies? And if so, what methods did you use?

I do not have any experience per se, but I do have experience with creativity sessions. These creative sessions could prove an efficient way to find applications for a technology, or, more specifically, organic molecules.
The sessions always have 4 phases: problem definition, idea generation, selection and idea improvement. The idea generation phase consists of 3 waves of ideation.
Important to define before you start any session is the boundary of your problem. A suggestion on how to do this is via the properties of the unit of analysis you are considering (in this case an organic molecule). The properties might lead to boundaries, and also towards an area of application/a direction in your search for applications.
In summary: properties → area of application → creative session(s) (there might be more than one session, in series or in parallel) → application.
You will always need creativity in this process. There are so much different creativity techniques that you can not use all of them. You could set 1000 teams to work on your problem, each using your own technique. It might also be good to have a "session" with yourself, just think about the problem for a few days/weeks/months. **A good question to ask myself for my framework development is how to select the creativity methods that best suit my need/suit organic molecules.**
It is in some sense a trade-off between time and people. On top of that, it is definitely a social process. So, it might be good to start thinking about a problem by yourself, but eventually its about bringing people, problems and solutions together. Innovation is often a combination of two or more already existing things. Making the connection is the goal of a session.
Now in this process of a session, it is important to keep moving and sometimes to just take a decision rather than ponder on it.

A question for me to answer might be "how to adapt a creativity session such that it can be used to find applications for an organic molecule?"

An interesting example of a technology finding a new application I find is the case of the filters that ESA used in space. In their process, they at first let go of the product, to look at trends on earth. The next step was to connect the product to these trends and in that way find new applications.
Another method they used was listing all the strong points and weak points of the technology and look for an application with every strong point.

There are a lot of different creativity methods, some more difficult than others. A determinant of the effectiveness of the methods is the participants' experience with sessions and methods. One could use several sessions, to let the participant learn about how easier methods work before using the more advanced methods.

A last aspect of a technology to consider before you start looking for applications is its maturity: at what level of maturity do you start looking for applications of a technology? In extension of this, a session might be a good way to find the holes in the knowledge about your technology.

Is there any literature I should read on the different subjects we just talked about?

Yes, the book “creative facilitation” [68]. Also, the book “myths of innovation” [94].

May I approach you again in a later stage of my research?

Yes.
Is there anyone you can think of that I should interview too?

Yes, Andres Hunt, I will contact him for you.

D.4 Interview prof. dr. ir. F.E.H.M. Smulders (candidate 4)

N.B. the interview was held in Dutch and thus has been translated. On top of that, this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

Have you ever had to search for applications for something new?

Yes, I have some experience with this. Let's start by distinguishing two different scenarios: either you invented something for a specific reason, so you already have a application or at least a direct, or you want to find an alternative application for something that already has some application.
In my experience as a management consultant, think 20 or 25 years ago, finding new applications was always done via creativity techniques.

I've started on my literature study, and when I try to look for papers threating methods to find applications for "something", I find there are very few papers on this subject. Can you comment on that?

Yes, first I would change the word "something" to "a technology". This can be for example be contrasted to "technological knowledge", where a technology is already more finished or ready than technological knowledge is.
Also, look into the course by Hartman "turning technology into business". During the course, participants get patents from the Delft university and they have to find applications and formulate business ideas based on these patents. I don't know which tools he uses, but you should definitely interview him.
Apart from this, I do think you are right, probably there is not a lot of literature on your subject. There are a few models, one of them from your own faculty of TBM, called "integrated innovation model".
Look into the integrated innovations model.
There is a lot about implementation after finding the application, but that's not your subject. I don't think there has been a piece of systematic research into how people found the applications for a technology.

This is also what I found so far. However, you would expect there to be a lot of research into this, right? I mean, it is something that happens a lot.

Yes, I agree, I think it might be something that happens every day. But maybe because it happens every day, it is something that has been locked into the daily practices and is as such not recognized as a possible subject for research.
There is, however, some research on serendipity. Serendipity is finding something you weren't looking for. It is about starting out without intention for a certain direction but then a direction arises. Another direction you might look into is literature on how inventions came to be.

Let go back one more time to the original question. How to find applications for new technologies or new inventions?

You might use patents to find applications (although this is more a method to find technologies).
Do you know TRIZ? This might be a useful tool.
I think finding applications for technology always needs to have a direction (a direction into a certain application field). There needs to be a direction, because otherwise the ideas that come from your creative sessions are numerous and useless.

Apart from that, you need to always reason from what a technology can do into the possible (alternative) applications for the technology.

I do think, however, that the subject of your questions as you formulate them now has been formulated to broadly. I think Roland will tell you that you need to formulate an application field.

I added a word card “properties” to our model. Could it be that via looking at the properties of a technology you might formulate an application field?

Yeah, sure. I would like to reformulate, or add, that it is about **“intentional search”.** On top of that, I think if you want to do this thesis right, you had or have to do the industrial design course “creative facilitation”. The teachers of this course have practical experience in using different creative methods and know you to facilitate session for these methods.
Maybe interview some of the teacher of the course “creative facilitation”?

Finding applications for something that you have, for example, made by accident is design. It’s the conceptual puzzle before you get a new integration of elements that were not connected before. This connection of elements (people, time, place, idea, etc.) is what invention is.

Let’s pose it differently, lets imagine a research group where they do fundamental research. Now they find something, without much context. How to find applications for this new something?

Well, the answer is brining people together, having creative sessions. A good example of this, is the 3M sticky notes.

Now let’s have a look at our framework. I put in the “intentional search” before the “creative techniques”. What do you think about that?

Well, I think the “intentionality” is there throughout the entire process. There is always intention, but not always focus. Through intention you find something of which you think “this might fit”, then there is focus, and you get focused creativity.
There are several forms of creativity: intentional creativity, focused creativity, converging creativity (to make sure you can actually produce your invention). This is not the same as selection methods, it’s more about ideas on how to get the invention to the market. Also look into rational creativity and Herbert Simon. Although maybe that is more engineering’s creativity, where you have a toolbox with solutions and you match each problem with right solution or right combination of solutions, which is not really finding applications for something new.
Also, have a look at **co-evolution and design.** I will send you two papers about it.

May I approach you again in a later stage of my research?

Yes.

Is there anyone you can think of that I should interview too?

Yes, dr. D. Hartman.

D.5 Interview prof. ir. D.N. Nas (candidate 5)

N.B. the interview was held in Dutch and thus has been translated. On top of that, this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

Do you have any experience with finding applications for new technologies?

To do this, you start with a technology and you translate this technology to benefits. The next step is to determine for which applications these benefits provide an advantage and from here you translate the benefits into concrete products and services.
The benefits you determine by talking to experts. Important here is the dialogue between you and the experts, because both parties on their own probably will not be able to determine the benefits.

With what kind of experts do you need to have this dialogue?

The experts of the technology, since these people know where the advantages of their technology lies with respect to other technologies. They know what the technology is capable of. However, since they have a certain distance from industry, they most likely do not know what is demanded in industry and thus what might be good applications.

Do you have an example of a technology that found its application like this?

Yes, currently we are in the middle of this process with quantum technology.
An example from history is the laser. When it was first demonstrated, people did not know what to do with it. They were thinking about weaponizing the technology, but nobody thought it could be used to laser someone's eyes or scan groceries.

Are there other ways to find applications for a technology?

Yes, you could use brainstorm/creativity methods.

I have had an interview with Dr. ir. Smulders recently, and he said that you always need an area of application to start with, and from there you can use creativity to find applications.

You do not always need an area of application. I would say you start by finding the benefits we talked about before and from there define or search for areas of application.

I find it hard to disconnect the benefits and an area of application. Take for example the benefits of a laser, which we just said are sharper edges, no saw loss, higher precision, etc. These benefits are more or less specific for the area of application "cutting", right?

Well, then we have to talk about the **definition of an area of application**. I think an area of application is more an industry. If you talk about cutting, you do not talk about what you are cutting.
You find the benefits through thinking about cutting, but the benefits exist on themselves (without the context of cutting). These benefits might in turn lead to other areas of application. For example, you could think about where else (apart from cutting) you might need a high precision.

So, you go from area of application (cutting), to a benefit (high precision), towards other areas of application (how could I use, or where do I need, high precision). So where do the experts fit in this picture?

You talk to experts, you ask them “what is the benefit of this technology?”. They provide you a list of benefits that are with respect to a certain area of application, for the lack of a better word. Possible areas of application could be cutting or burning. Now starting at the listed benefits, you can try to find other areas of application.

So, to summarize, you either find applications via the “experts dialogue” route, or via the “creativity methods” route?

Yes, and on top of that you might look into how science fiction writers approach their work. They often look at the future, together with scientist, and they translate this into a certain view that makes up their story.

Do you have any literature to substantiate the two or three methods we just talked about?

No, but I have never looked for this literature. However, the experts’ methods we talked about goes from concrete to abstract to abstract to concrete, which is the same tendency the TRIZ methods follows. SID does this too, but this is a derivation from TRIZ. I think TRIZ works better for your case.
TRIZ is similar to the method we talked about, but it is not the same. So, you might list it as a third method.

Are these two or three methods than the only two or three methods we could use?

Well, you could probably come up with more. On top of that, creativity methods are almost endless. So, do you approach this as one method, or as multiple methods? This depends on which level you want to consider your methods.
Another method you might consider is looking at artists, to let yourself be inspired by their output. You could use this output as a starting point for a creative session.

Before you started working at Delft university, you had some experience in industry in the area of new business creation, right?

I’ve worked for Philips, KPN and I have had a consultancy and innovation firm for 16 years.

And from this work experience, do you have any experience with finding applications?

Yes, for example with the LED. Did you do the course on road mapping?

No, I did not.

In this course they talk about the 3-horizon model from McKinsey and the road mapping format. This 3-horizon model gives three timeframes (3 horizons): going concern/mature business, rapidly growing/upcoming business, emerging business. Have a look at these two models, they might help you. You can find them in the book **Design roadmapping by Lianne Simonse** [95].

During your time in the consultancy business, did you always search for applications in the way we described before, via experts and the benefits?

Well, we always had team in which there were several experts. With this team we would have several sessions and steps to take in the process.

Were these steps always the same?

Well, the process had the same structure. We would always start with a proper analysis of the current state of the technology. After that you would talk to experts and an external analysis. The next step would be to summarize this into a model of the technology. Next, we would go into a workshop with the team, to define a strategy, and another workshop, on creativity. A third workshop would be on the value proposition. Lastly, we would test the value proposition with the (potential) customers, either qualitative or quantitative. This very much looks like the industrial design approach.

However, the start and end of the process are inverted with respect to what I am trying to find.

Well, you start with a capability and not a customer need, and then you try to find a problem to solve with this capability.

In the industrial design approach, you start with a problem and try to find a solution, right?

Well, you first have to find out what the actual problem is, since the customer rarely states the real problem.
So, for your knew technology, you go from an area of application (cutting), to an application (a versatile cutting tool for in workshops) and then you start with the normal industrial design process. So, the approach to find applications is the industrial design process, with something before it.
Search for "design thinking approach" to find out more about this.

Something else, what is your unit of analysis, the organic molecule? What can you do with it?

That's a question with a lot of answers, organic molecules are applied in a very broad range of applications.

This is a very broad subject. Why did you choose such a broad topic?

That's historically motivated, considering my first master thesis.

So, you starting point is a molecule for which we do not have an application yet. You might want to look into the development of machine learning in combination with organic synthesis. You could try and talk the companies that are working in this field and find out how they approach the search for applications. A good example of such a company is **Zymergen**, a start-up in this field.

Anything you would like to add to what has been said so far?

Yes, use **Miro online whiteboard** instead of google docs.

May I approach you again in a later stage of the research?

Yes

D.6 Interview ir. J.H. Welink (candidate 6)

N.B. the interview was held in Dutch and thus has been translated. On top of that, this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

How do you approach the finding of applications for new technologies?

I am wondering if I am the right person to answer this question. However, I would not exactly know who the right person would be.
And another remark I want to make is that I think finding applications for organic molecules, something that already exists, is very different from finding applications for a new technology. The search for applications for a new technology is a search in all direction.
It is important to think about in what dimension you want to have your answer to the question (for example, material vs product).

One way I search for applications is asking help from groups of students → creativity.
Another way you could approach the search is creating a list of possible applications and try to match a new technology to one (or a few) of these applications. This list is something that develops over time.

When writing your research proposal, do you ever come across technologies for which you need to find an application? And if so, how do you approach this?

Yes, and mostly these challenges resolve themselves in the coffee corner where I can talk to colleagues.

Is there any order in these processes or different methods?

No, these methods happen in sequence, in parallel and everything in between. This is inherent to the methods, all the human aspects of the methods make them capricious. For example, a brainstorm: sometimes you know after a minute what the solution has to be, but other times you need an entire week.

Is there any method inherently better than the other?

No, every method has its place.

D.7 Interview ir. P. Vercoulen (candidate 11)

N.B. the interview was held in Dutch and thus has been translated. On top of that, this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

Do you have experience in finding applications for new technologies?

Well, before I answer that, let me say that I find it usually happens the other way around: you develop a certain technology with an application in mind.

Could this be the difference between applied and fundamental research?

No, I think this is more about the difference between product development and commercial success. So, I think the problem is really about finding the application that could be a commercial success.

However, my thesis is not really about the fact whether an application will be a commercial success, but really about finding an application.

Then I would like to refer to my experience in the field of material science, where you look at the properties of a material to determine a possible application. So is about the relation between structure and properties. **Look up the literature on "relationship structure and properties", for example a book about coatings, or a book about composites.**
Take for example unsaturated polyesters. These are not known for their excellent photo resistant properties, so developing a durable coating for outdoor applications from unsaturated polyesters is out of the question.
This way, we know the favourable and the unfavourable properties of every class of molecules. If you create a model where you put in the different classes of molecules with their possible applications, add the known structure/properties relationship and refine this model with test cases (molecules that already have their applications), you might end up with a model that is capable of finding applications for new molecules.

Then I would like to ask about a definition, what is the difference between a molecule and a material exactly?

Well, a molecule is a building block and a material is composed of building blocks. Molecules is micro level, materials is macro level. Of course, exceptions exist, where a material is very homogeneous from a molecular perspective. I assumed from your email your unit of analysis is a molecule, not a material.
I believe you could develop a molecule by chance, but you cannot develop a material by chance. Developing a material takes much more coordinated effort.

Yes, my unit of analysis is a molecule indeed.

I have been working in the fine chemical industry for a few years, where I learned the story of how aspartame was discovered. This is an interesting example of a molecule that found its application by chance. **Look up the story of aspartame.**

We talk about classes of molecules. Any idea how to define these classes?

If you take up any organic chemistry book, you should be able to find this.

Let us summarize up until this point: we have talked about to find applications for materials, which might be translatable to (some) organic molecules. You will always have to look at the properties of a material and the relation between structure and the properties to find an application.

Not exactly true. Its more that you will have a big chance of finding your application in that direction, if there is an application, and even then, success is not guaranteed.
An area where they are trying to play this game, is the refinement of waste streams into usable substances.

Here they get a certain material or molecule out of a waste stream and they have to find an application for this material or molecule. An example of this is the molecule FDCA (2,5-furandicarboxylic acid). Among other, the company Avantium is trying to find an application for this molecule. An old colleague of mine works there, Marcel Lubbe. **You might want to ask him how they approach the search for applications.**

Can you think of any other ways of finding applications, apart from the ones that on our wordcards already?

Yes, high-throughput experimentation. You just start to look for possible applications by trying "everything". I would say this is the less intelligent way of finding applications, as opposed to the way via structure/property relations.
Also, I am wondering what to do if you really do not have any idea for any applications. What would then be the approach to find applications? I think the only way here is this blunt force, "just try" approach.

Could the answer maybe a combination of the two? First you find some properties (assuming you know what properties you need to find) and this gives you direction. Now you can start to use the blunt force more intelligently and search in this direction.

Sure, but then the question still is, what will you be trying? And on top of that, this might very much limits the areas in which you try to find applications, which could be a serious downside of this approach (since you do not exploit all the potential of a material/molecule).

Maybe a solution to this problem is finding those properties that are needed or desirable for a certain area of application. If you can put this in a database, you can create a matching system between new molecule and possible application via the properties.

Sure, but the question of measuring of the right properties is really a thing. Probably any expert only knows the relevant properties for his/her own area of expertise.

Maybe you can solve this with the same model, where you can look up which properties you need to measure for a certain area of application.

To conclude, anything you would like to add what has been said so far?

No.

Is there anyone I have to interview, apart from Marcel Lubbe?

Yes, Reinier Grimbergen from TNO.

May I approach you again in a later stage of my research?

Yes.

D.8 Interview dr. P. Lips (candidate 12)

N.B. the interview was held in Dutch and thus has been translated. On top of that, this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

Do you have any experience in finding of applications for new technologies?

I have thought about the question as you phrase it in your email, and the first thing that comes to mind is the situation I have been in several times where the customers ask a company to solve some problem. This is the opposite, or the other way around compared to your question. What I see a lot in that situation is that people try to re-invent the wheel very often. It is a good idea to look at other industries, to see how they solved similar problems, and copy-cat from that. This is something I do have experience in.
Finding applications is maybe something I have done during my PhD. During my PhD we were creating a foam material, for example for the automotive industry. However, I also looked into a totally different application field: the medical field. Originally, we came to this idea via a discussion in the research group. The contact between different people in the group was facilitated in the form of weekly meetings. How it happened exactly I do not remember. Probably, I gave a presentation about the foam, the properties and I showed a SEM image of the foam (It is probably important how you show the properties material, an image might be a very fruitful way to foster creativity. On top of that, showing properties in a way that they are usually not shown might also yield new ideas. This could be seen as a very **unsystematic way in an otherwise systematic method**.). This led a fellow researcher, who was doing research in the medical field, to think about possible applications in the medical field. When the idea was born, it was very handy that we had a close collaboration with the university of Pisa, who have a lot of experience with *in vitro* and *in vivo* testing.
So, to summarize, it was probably a good combination between the right types of different experience and research areas in the group, in combination with the right connections (with the university of Pisa).

Let us now try and translate this into the beginning of a framework in the form of wordcards. I summarized the method up until now into the trinity of contact with experts, creativity and properties, would that be about right? (N.B. it might be useful that the experts are from different fields to foster creativity).

Yes, roughly. After the initial idea, I started to read more about the proposed area of application. I also started to do some experiments for myself. After that I sought contact with experts again, and here it is important that these experts have relevant experience in the area of application, to come to a concrete application.

[more of the conversation at this point has been summarized in the framework that was created from the content of this interview]

Another important aspect in finding applications is persisting in the ideas you have.

We have talked briefly about looking at other markets or segments before, in the context of going from application to design. Can we also invert the direction of this approach?

Well, the experience that I have with that is that my background in certain fields has led to alternative applications of innovations when I was working in other fields. So at least from a personal experience we can invert the direction of the approach. In the experience I have with this, the starting point was a patent.

Is it justified to say that the patent was in that sense a replacement of the trinity we talked about before?

Maybe a patent primes you for the idea that applications or alternative applications might exist. So, in that sense, yes.

[the next part of the conversation is summarized in the second framework, or second part of the framework, that was created during the interview]

Something that strikes me about the second framework is that the point of origin is very different: there is a patent, so probably someone had a very clear idea of the application of the technology for which the patent was filed (usually, people only get patents on stuff they think they can make money on). For there you start to look for alternative applications for the technology.

We have talked about a lot of different things that are involved in the process of finding applications. Any literature that you would recommend I read after doing this interview?

Well, for the process of finding the application, you might look at my PhD thesis. Another thing you might look into is how the sports innovation collective approaches their innovation, you can probably find that on their website (sport innovator).

Is there someone you know that I should interview next?

I know someone in the world of sports innovation, **I will approach him for you.**

May I approach you again in a later stage of my research, to test the framework?

Yes.

D.9 Interview dr. ir. G.M.H. Meesters (candidate 7)

N.B. the interview was held in Dutch and thus has been translated. On top of that, this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

Do you have any experience in finding applications for a new technology?

I remember something from a conference I went to some time ago. There was someone who had method to systematically look for the applications of organic molecules. I will try to find out who or what that was.
Apart from that, if I would have to find an application for a molecule, I would start by devising categories for these molecules to order them. This could be done based on properties or based on molecular structure. One example is the molecular fingerprint. You might want to **look into the electronic nose developed by the university of Wageningen.**
Now if you have these categories, you could link the categories to certain applications, or areas of application. This matching process is nothing more than a decision matrix.
If a molecule fits in multiple categories, you might want to assign weights to the molecule in each category, so to know which category is most clearly featured in the molecule.

I think that at this stage, organic molecules as a whole is too broad of a unit of analysis. If you really want to develop a method that yields applications, you should narrow it down. A good subcategory might be flavours and fragrancies, since these molecules have been defined relatively well already. Another option is organic solvents. Thirdly, you could narrow it down by limiting the total number of atoms in the molecule, or the number of different atoms.

Another method you might use, or adapt for use, is the house of quality. Although this considers the process the other way around (from application to molecule), it might be adapted for finding applications.

Someone who might know about how to find applications and who is definitely very creative, is Steven Picken. He is very skilled in translating a demand into a molecular structure. On top of that, he is working on a project where they are looking at molecules in wastewater.
The organisms in wastewater make all kinds of molecules. In the project they are looking for applications for these molecules. **Another person involved in this project is Mark van Loosdrecht.**

Do you have any contact from your time at DSM that might know how to approach the search for applications?

I will think about that.

May I approach you in a later stage of the research?

Yes.

D.10 Interview dr. L. Hartmann (candidate 8)

N.B. the interview was held in Dutch and thus has been translated. On top of that, this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

Considering you teach the course "turning technology into business" at the Delft university, how would you approach finding an application for a technology?

This process starts with a technology, often in the form of a patent, because a patent clearly states what the technology can do. As quickly as possible you have to describe what you can do with a technology, on a high level of abstraction. The level of abstraction is determined by the boundaries of the core of the technology: how far can you abstract while the working principle of the technology stays in place.
A good way to approach this description of what a technology can do is to answer the question "we know how to" for the technology.
After formulating this description, the next step is a creative process in which possible applications are formulated, using the just formulated working principle of the technology.
A diverse group of experts is wanted up until this stage, to both foster creativity but also have a lot of information and connections in the same room.

When trying to find an application, it is important to talk with a lot of people. When you have a initial idea for an application, you want to talk to people within this field of application and ask their opinion. Now you can improve or change your idea with every person you talk to. On top of that, you can let each person tell you who to talk to next, getting closer to "true" experts.

Now summarizing what we have until now into the wordcards, your starting point will always be a patent…

The starting point is a technology and it can prove very useful if this technology has already been formed into a patent. A patent is always a technology, but a technology does not always have a patent.

And from this starting point you have to answer the questions "we know how to" for the technology, formulating as abstract as possible what the technology can do.

Yes, exactly.
Now during the course, sometimes the problem owners decide at the end of an application finding process, the solution needs to be something different than described (by the patent). This is not really a process of finding an application, but more so a process of finding a technology to a certain problem: getting inspired by a certain patent, but via current problems that need to be solved ending up at another technology to solve this problem.

We might be able to extract a way of finding applications from this: you could patent your technology and just send it out to companies, to see whether they have problems that could be solved with this technology.

Now the framework that we have so far, did I miss anything?

Depends on how much you want to put in there. Something that I'm missing is that the diversity of people doing the creativity is very important. On top of that, you need people that have been properly trained in creativity. A challenge in this phase is to keep engineers away from doing what engineers do best: understanding the technology and wanting to improve it. For this, you have the expert who invented the technology and/or filled the patent.
During your creative session, you just think of every idea possible. After the creative phase, there is a selection step. In this selection step, you can contact the inventor/expert and ask whether the possible applications found in the creative session are possible.
Another thing you might want to include in your framework is the concept of the lead-user principle. This idea, developed by Eric von Hippel, states that there are certain types people that come up with solutions for their problems. If you can find these lead-users and talk to them, you can let them help you develop the application you found into an actual product.

I do not know yet if I will include this in my thesis, since the initial goal is finding applications, and not creating business from these applications.

I understand you have to set boundaries to a thesis project somewhere. So maybe you just want to find applications and make a first selection within these applications. Then you might want to think about selection criteria for this selection step. Some things that have an influence are size of the market, growth potential of the market, accessibility of the market.

Right, so the market already has a role in the framework before the final application is selected. I have to think about how I will include selection of ideas in my framework. For now, I'll add lead users and business to my framework.

The method we have so far, the method you use in your course, do you have literature to back this method up?

Well, maybe, but I do not really care the science behind the method. It is nice that is has been backed up scientifically, but I care about if it works or not. **I do have an article that I wrote on my method**, I will send you this article.

Is the method we have now the only method you know to find applications for a technology?

I cannot think of any other method, but that might have to do with the fact that I am right in the middle of using this method for my course year after year. On top of that, wherever I have been and have talked about this method, I have never had someone tell me "this looks like method X I know" or "I have a completely different approach to find applications".
A book you might read is **Loonshots by Bahcall** [96].
On top of that, you might want to interview the people who set up the course I am teaching: Daniel Kapitan and Cees Bijl.

May I approach you again in a later stage of my research?
Yes

D.11 Interview dr. R.F.P. Grimbergen (candidate 13)

N.B. the interview was held in Dutch and thus has been translated. On top of that, this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

Do you have any experience in finding applications for a new technology?

Yes, I do have experience with that, but mostly I work the other way around, starting with a demand from a client. We are talking about technology push vs demand pull. You are asking about technology push and I usually work with demand pull. The art is to integrate both approaches.
I think solution providing is something you always have to do in collaboration with the clients.

Fair enough. However, sometimes inventions are technology push (for example the iPhone).

Yes, but they are the exceptions. The chance you can make that work commercially, that you can create a customer need, is small. To be successful, you better focus on demand pull.

However, for my thesis, I want to consider technology push. Do you have any experience with that?

To find applications for a molecule, you have to start with the functionalities of the molecule and look in the market for a problem that can be solved using these functionalities. Now the question is how to match the functionality with the person in the market that is looking for this functionality.
So, you start with the properties, from the properties you flow into a functionality (this might be a step you can accomplish with TRIZ). The difference between a property and a functionality is maybe a bit semantic, but an example would be that a property is something along the lines of “melt temperature”, while a functionality is “UV absorption”. **Maybe it is the difference between something a molecule inherently has and something a molecule can do?**
A challenge here is that you do not know which properties are relevant, so you have to establish a sort of “minimal set” of properties that you measure for every molecule you want to find applications for. Your properties often function as boundaries to the possible applications you have.
From this functionality you move into an area of application. You want to create a kind of property/ functionality mapping that you match with possible areas of application. **What does this mapping look like?** There are several ways to take that step: patent mapping, creativity, big data analytics and/or AI/machine learning. On top of that, maybe TRIZ also works for this step, but I am not sure.

I would use the patent mapping or big data approach first.
With patent mapping, you can digitally screen a lot of patents on functionalities of patented technologies (tools to do this already exist). These patents often include applications, so the results of this screening can be matched with the functionalities of your molecule, to find possible applications or application areas.
With big data analytics, or I actually mean web crawlers, you do the same as patent mapping software, but for the entirety of the internet. So, patent mapping software searches in IP databases for the search terms you provide it with (for example, certain functionalities). Web crawlers do the same, but the cast a wider net, a net over the entirety of the internet. **I will send you a link about this.** The information from this link also talks about artificial intelligence.

We now have five methods to go from a functionality to an area of application. Could you rank these methods?

I would start with big data analytics, maybe supported with patent mapping. How you approach this could be your creative process (how smart you formulate your search terms influences the results you get bigtime).
You need domain knowledge to separate good and bad results coming from the big data approach, big data can not do this for itself.

Another thing you might want to take into account is how to get everyone to agree upon an application. Usually, when a search for an application is conducted within a company, people will not agree straight away. The person who is most convincing in this sense would be the person that is able to connect a value proposition to the application very early on the development.
On top of that, this value proposition is also a go/no go criterium, albeit a complex one (how much does the customer want to pay, how much does it cost me and what is the difference).
Other ways to rank the possible applications you have found are the ability to execute that a company has, the freedom to operate, access to funding and required competences and/or partners.

Anything you would like to add to what has been said so far?

The framework we made so far looks pretty complete. I would add that until you have found the area of application, the process is mostly divergent, after that it is mostly convergent. I would add this in some way to the framework.

Do you have anyone in mind that I should definitely interview?

Yes, Ubald Krachten.

May I approach you again in a later stage of my research?

Yes

D.12 Interview prof. dr. S.J. Picken (candidate 9)

N.B. the interview was held in Dutch and thus has been translated. On top of that, this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

I have heard from Gabrie Meesters you are working with a company that is trying to identify and find applications for organic molecules in wastewater. Does this mean you have some experience in finding applications for organic molecules?

Yes, let me illustrate this process. In this case, nature delivers. You start with a question that requires a solution. You can translate this solution into properties. You try to roughly formulate chemical structure that provides this solution or these properties. Depending on the demands you have for the properties, you have more or less options for your structure.

For my thesis, I am searching for the process the other way around.

It is a process that develops over time. It is not something people do on their own, it is a collaborative effort (where the participant could be aware or unaware of it). A collective knowledge develops over time by contact between people (conferences, lectures, etc.) and from that collective knowledge, possible applications arise.
A good example of this is the conducting/charged polymers. This has been a purely academic topic for the longest time, but now they are widely used in for example OLED screens. It took a long time, and people, to commercialize the technology in a profitable manner.
There are also different types of people you need, one of these types being people that have the right mindset to “just do science”. Often these people are very creative and who know very well what is possible. On the other hand, there are people that very quickly start to think about possible applications of a molecule or technology. The interaction between these two types of people often leads to the first application identification. Now a third important type of person in innovation is the “bookkeepers”, people who grind through a lot of experiments to optimize and/or improve a molecule in a certain application.

Now let us put some of the topics of this interview in the wordcards. So far, we have touched upon the importance of structure and properties, maybe even their relationship. On top of that, we have talked about how there is a certain level of coincidence or synergy to creation of (area of) application trough collective knowledge. Do you agree with how I put this in the framework?

Sure, but let me add to that, you can go either from structure to properties, or from properties to structure. You can need certain properties and think of a structure to get these properties or start with a structure and measure the properties of this structure.

For my project, the starting point is a structure

I would put that in your framework, the fact that your starting point is a structure.

Creativity works two ways: starting from a structure or property reasoning towards an area of application, you could get stuck in one line of thinking. Creativity methods can help you identify other possible lines of thinking, or areas of application. Apart from that, you could reason further from a possible application you have found, where the current properties of the molecule are not optimal.

Now creativity could provide input on how to alter the molecular structure to make the molecule more optimal in an envisioned application.
These two ways of using creativity can work together to form a upward spiral, going back and forth between application, structure/property relationships and creativity to find a good structure for an application.
On top of that, there is an important learning effect in experiments that do not work. You need trial and error to learn what a molecule can do and can not do.

We now have a quite complete method to find an application for an organic molecule. Do you know any other methods?

Well, I want to add something to the previous method. With the creativity, there is also a certain amount of intuition needed. Sometimes as a scientist you let go of some of the scientific principles and follow your gut feeling on which possible applications to pursue, which are most promising.
It is a divergent process up until the identification of the area(s) of application, after that it is a convergent process, where you select the most promising application.

Is there anything you would like to add to what has been said so far?

I would like to add that there are a lot of different types of people, different personalities. Every type has its own strength, also in the search for applications. If you can include this diversity in your framework and a way to leverage it, your framework can reap the benefits.

D.13 Interview dr. S. Ghodrat (candidate 10)

N.B. this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

How would approach finding an application for something?

My experience with this is mainly in the field of materials, so finding applications for materials. I would start with literature (or other sources on the internet, for example YouTube), searching for the properties and limitations of the material. From there I will try to look for a way to introduce the material to designers, to make them aware of the material.
Something we might learn from designers is their way of doing a experiential characterization of a materials (as opposed to a technical characterization) by letting (potential) users interact with the material.

Where does this user interaction fit in the broader picture?

It is a process that can be done quickly after the technical characterization. The interaction with the user is something that can influence the final application, for example by users that provide ideas based on their experience with their material.

So, would you say that the process of user interaction is something that start early on in the process of finding applications and carries all the way to the end? On top of that, would you say it is something that could guide some part of a creative process?

Yes. An interesting piece of literature you might read is the literature on the materials driven design method, created by E. Karana.

I've had a brief encounter with the method in the past. However, something I am struggling with is defining the difference between the challenge of finding an application and the challenge of designing something.

Well, if we consider organic molecules, you create materials from these molecules. With these materials, you can design things. But you need to embed the molecules into something.

Now my question is, how to find this something?

As a researcher, I start with a very extensive literature review of the existing literature. Or you can talk to experts. Some people might directly go the lab to experiment, but I am not one of those people.
On top of that creativity is always an important aspect of these methods.
An interesting development in the recent years is the development of different databases of materials, their properties, their limitations and the processes in which they are used. One of these databases is Cambridge engineering software, or CES. Now if you make some new material, you can compare it to the materials in the database (for example, based on their properties) and see how the materials in the database are applied to find an (area of) application.

We've have talked about design quite a lot during this interview. How could I integrate the design approach into my framework that is built for organic molecules?

An important question to answer before I can comment on that question is: can I touch these organic molecules?

You can touch some, but definitely not all organic molecules.

That makes your scope quite broad.
Before anything, I would want to know the properties of the molecules. This includes both technical and experiential, but which one I would want to know depends of course on the type of molecule.

Maybe that is a step that I have to include in my framework, very early on in the framework: separate between the molecule you can interact with, and the ones you cannot.

It is not only about interaction, but it is about more properties. I suggest you create a list of favourable, less favourable properties and all the possible areas of application for organic molecules **(maybe link this to the properties)**. On top of that, you could look into the taxonomy of materials.

May I approach you again in a later stage of the interview?

Yes

D.14 Interview drs. S. Lohle (candidate 14)

N.B. the interview was held in Dutch and thus has been translated. On top of that, this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

How would you approach finding applications for a new technology?

What do you mean with technology?

In this stage, I am trying to define that term as broad as possible.

From my experience, you have two approaches to technology development: incremental and radical innovation. Finding applications for a radical innovation is something very difficult in my experience. To my experience, an application is only found when the technology has already been developed.

I think your question is very broad, you could give a wide variety of answers to the question as it is now. I find it difficult to answer the question.
On top of that, you cannot consider the search for application separate from the implementation of this application into a business. As I said, only when the technology has been developed (and formed into a product), the applications can fully develop. The applications are dependent on which obstacles have to be faced during the implementation.

But how can you reason towards an implementation when you do not have an application?

Often you have a scientist who discovers something and thinks of an application for this. Now this scientist goes (with help) to the industry, but the industry turns out not to be as enthusiastic. This can have all kinds of reasons, being technical, but also organizational or logistical.
Now it can happen that during the endeavour of the scientist in industry, he finds another possible application with a different industry. Now the industry is more willing to accept or apply the technology. So, there are several possible applications, but only a few get implemented.
What I also see in this is the way of finding applications by "getting out there", or seeing what things look like in industry to better match an application to this.
Finding applications is not the exciting part. The exciting part how to implement the application in the real world.

A possible approach to finding applications for organic molecules would be to look in which industries organic molecules find their application. Then you expand this by asking in which industries they could also be applied. Now you ask yourself why these molecules are only applied in the industries where they are already applied and not in the industries where they could be applied but are not. From this, you can see what the limitations of the molecules are and what possible blockades in the market are in places.

What you could do in your framework development is go to the faculty of innovation management at Erasmus university, talk to the people there. Amongst other, my old thesis supervisor/professor (who would not remember me, but that does not matter) Jan van de Ende still works there.

What is your experience in finding applications for new technologies?

I work at the technology transfer office; my responsibility is over the entire applied sciences faculty of the Delft university.

Do you have some sort of a standard process, starting with a researcher knocking on your door with some new technology?

No, there is no process. The different types of technology are to broad to be captured in a single process.
However, the IP department has a set way of finding applications for new technologies. If you want to talk to them, you could talk to Justin Kok.
I often have people come to me with a patent that often states an application. However, an application and a product are not the same. So, you have to find and use a good definition of application and distinguish that from a product.

So, in my framework, I would have to distinguish between a technical part of the process, of technology development and maybe the identification of possible applications, and a management process, of turning the technology in the actual products?

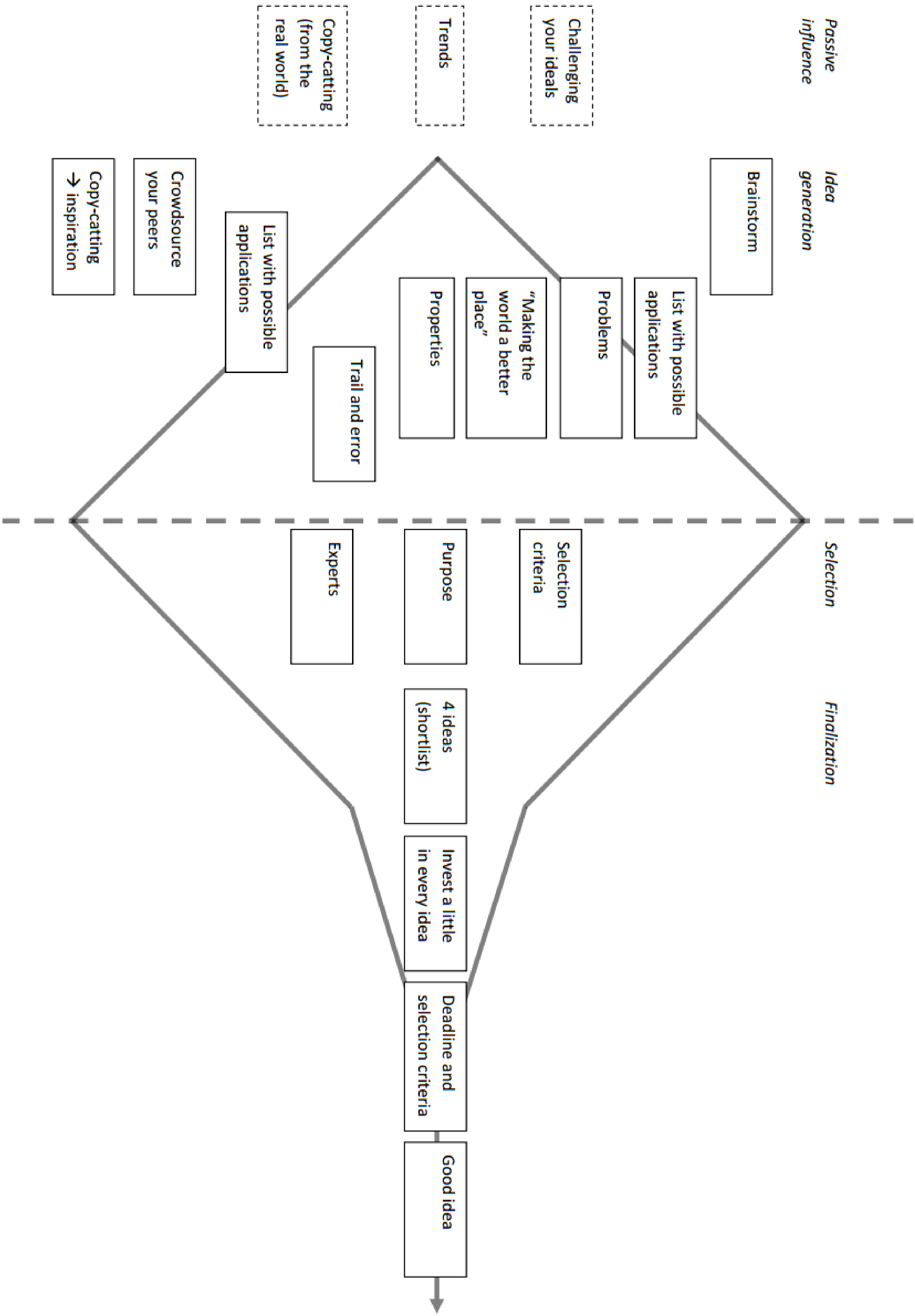
Yes.

May I approach you again in a later stage of my thesis?

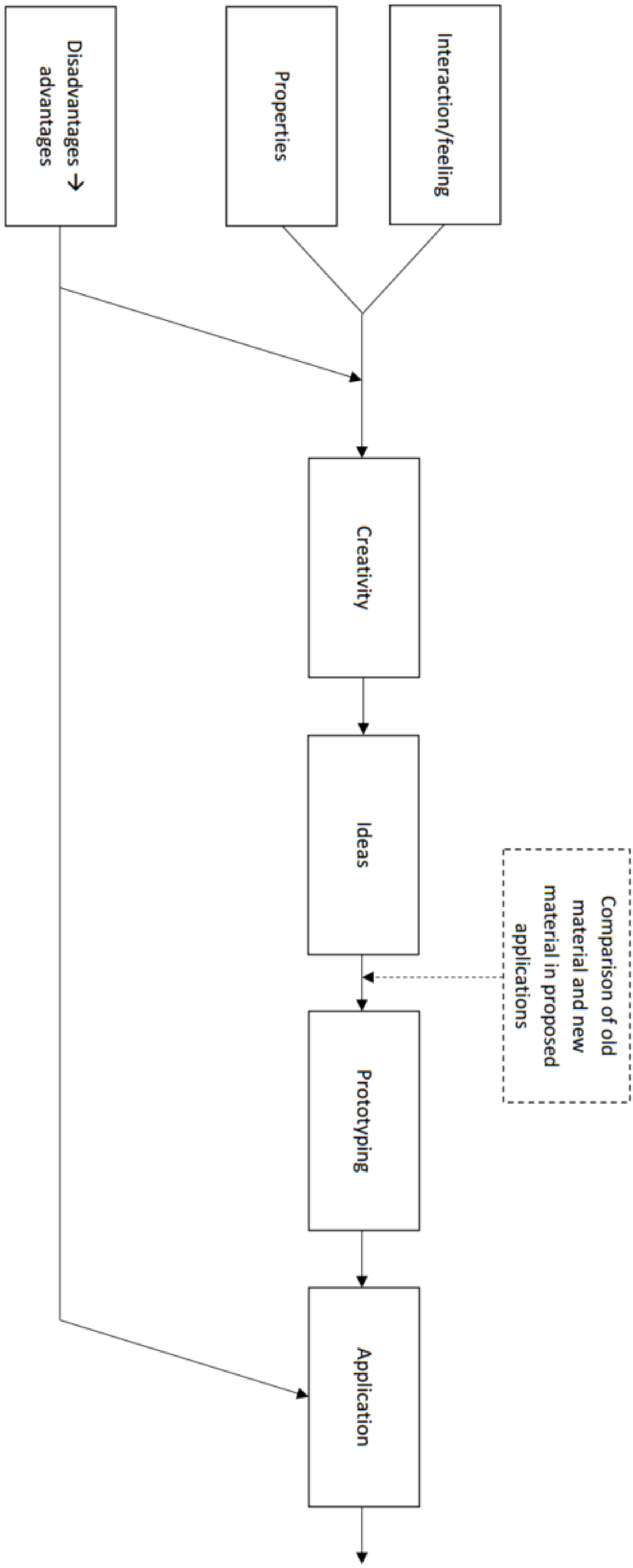
Yes.

Appendix E – Frameworks preliminary interviews

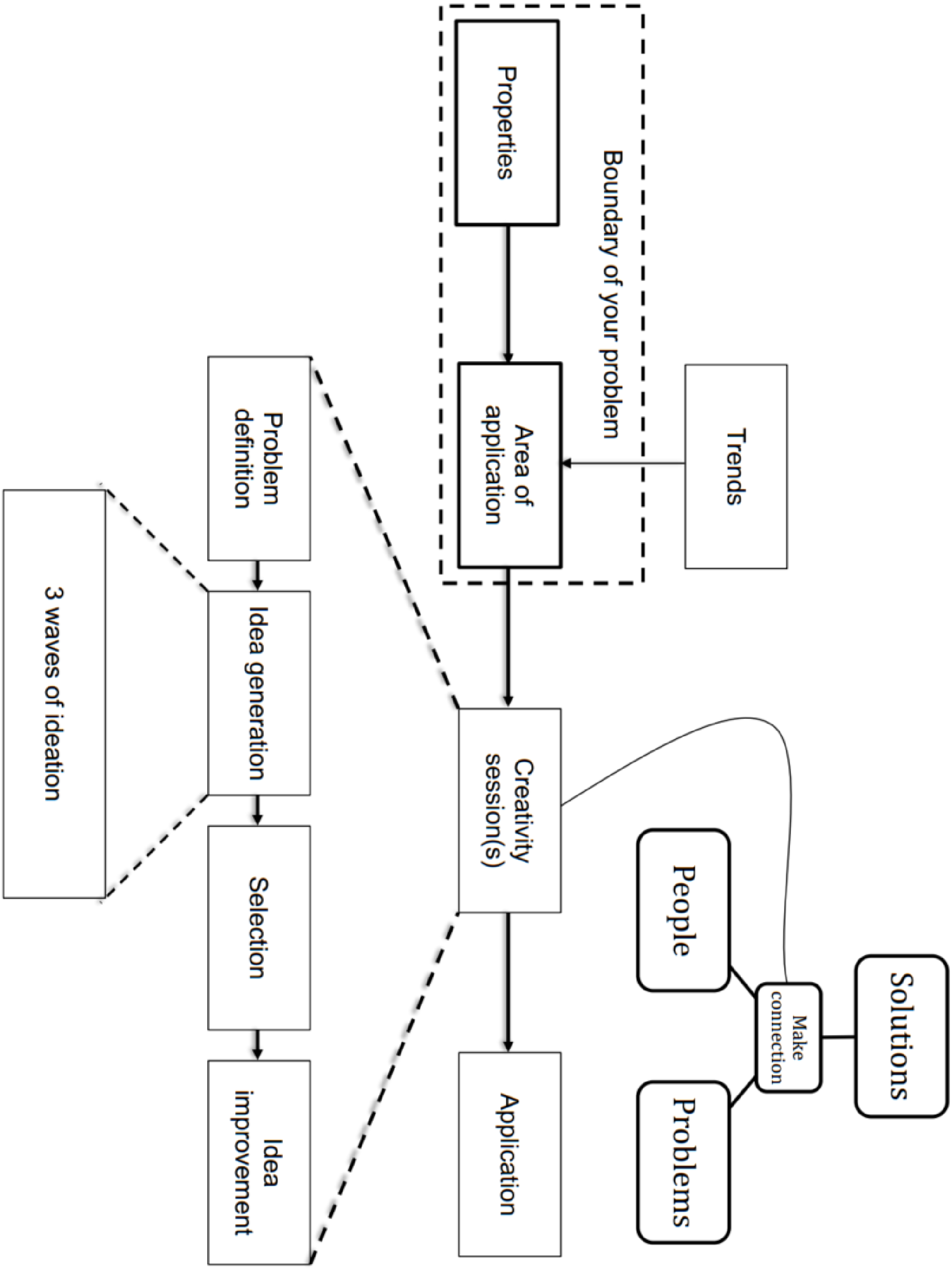
E.1 Framework I-010



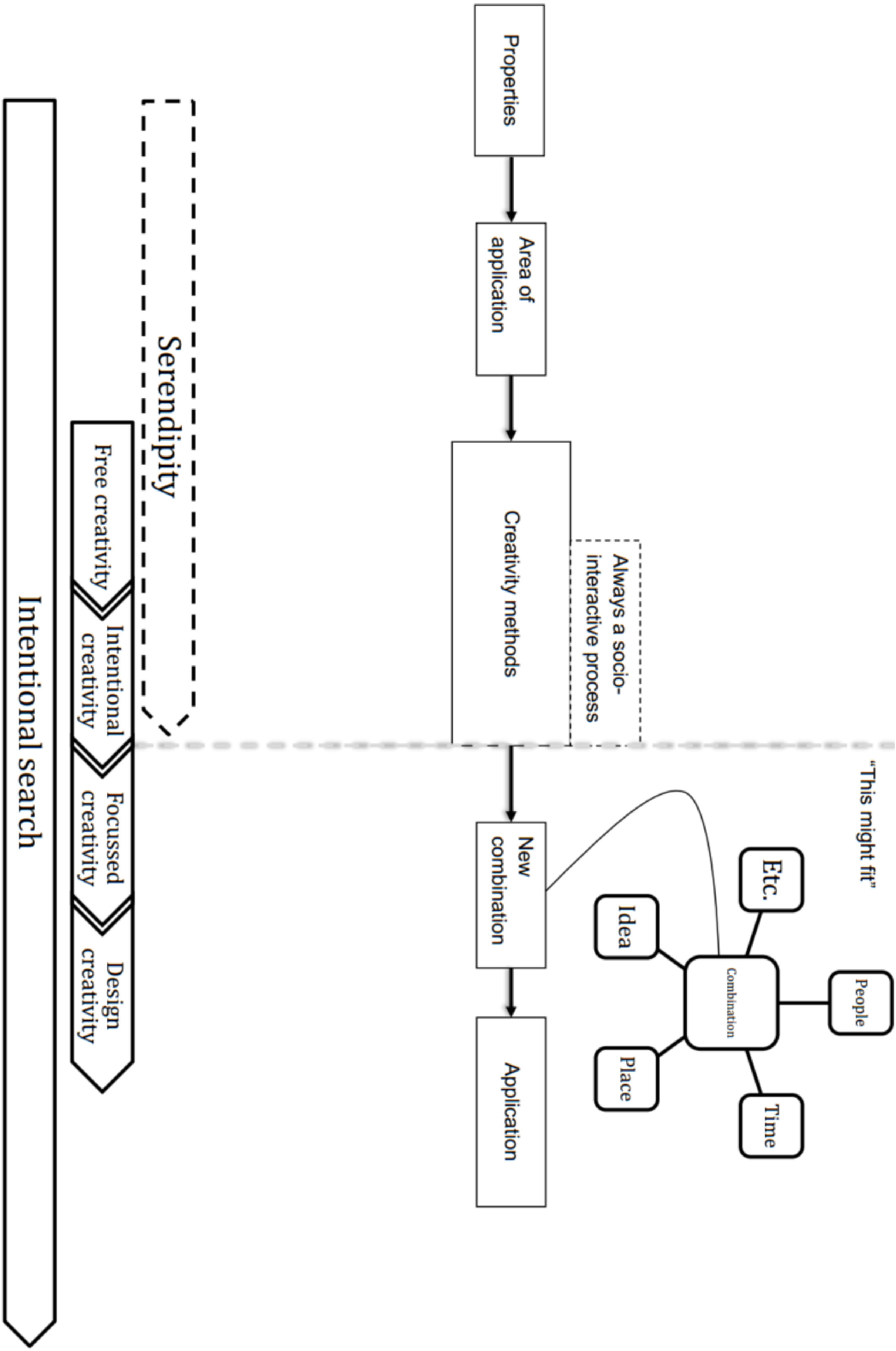
E.2 Framework I-020



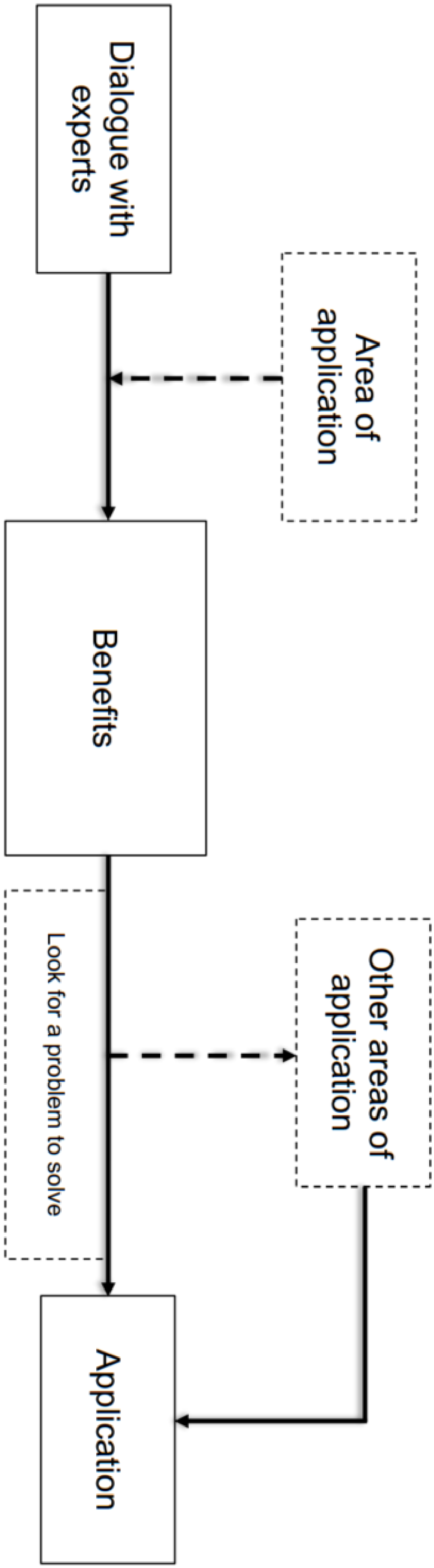
E.3 Framework I-030



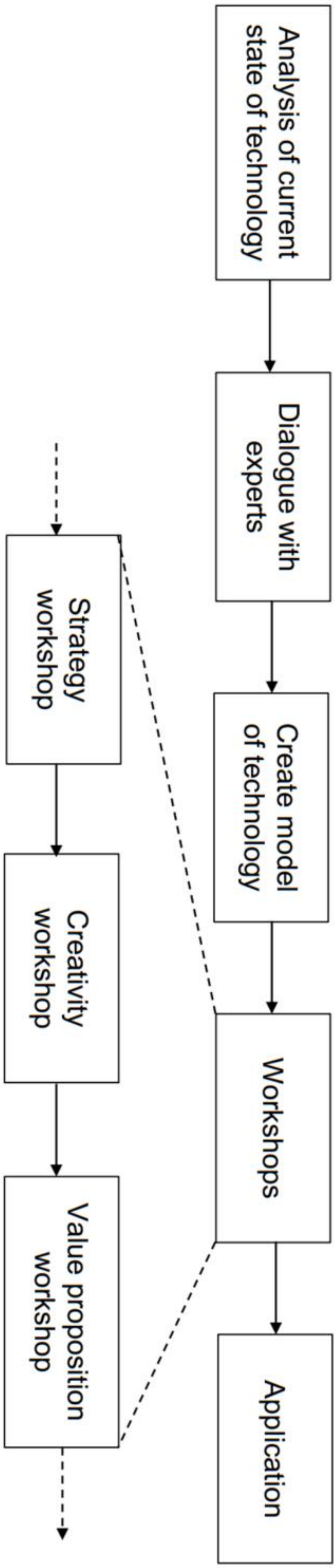
E.4 Framework I-040



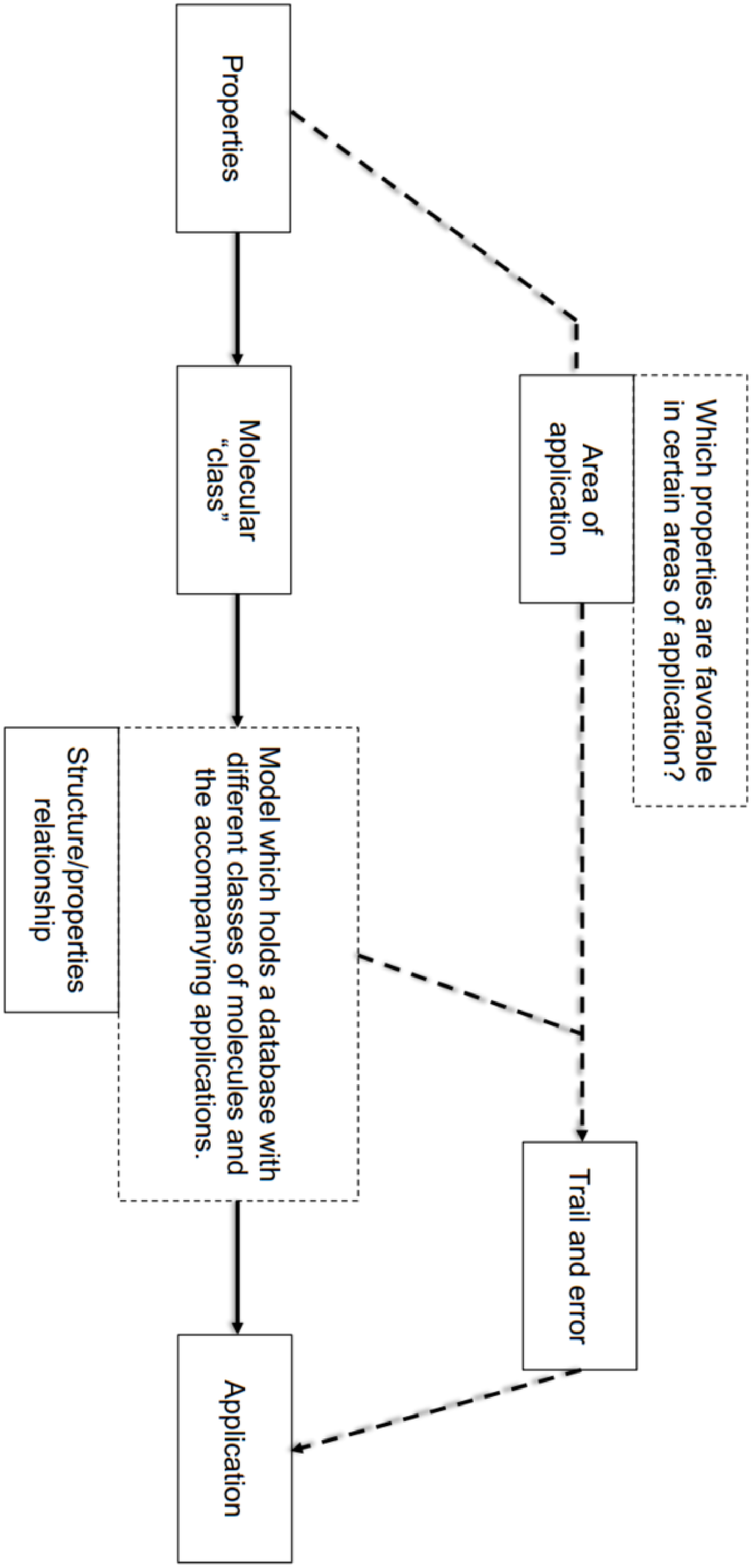
E.5 Framework I-050



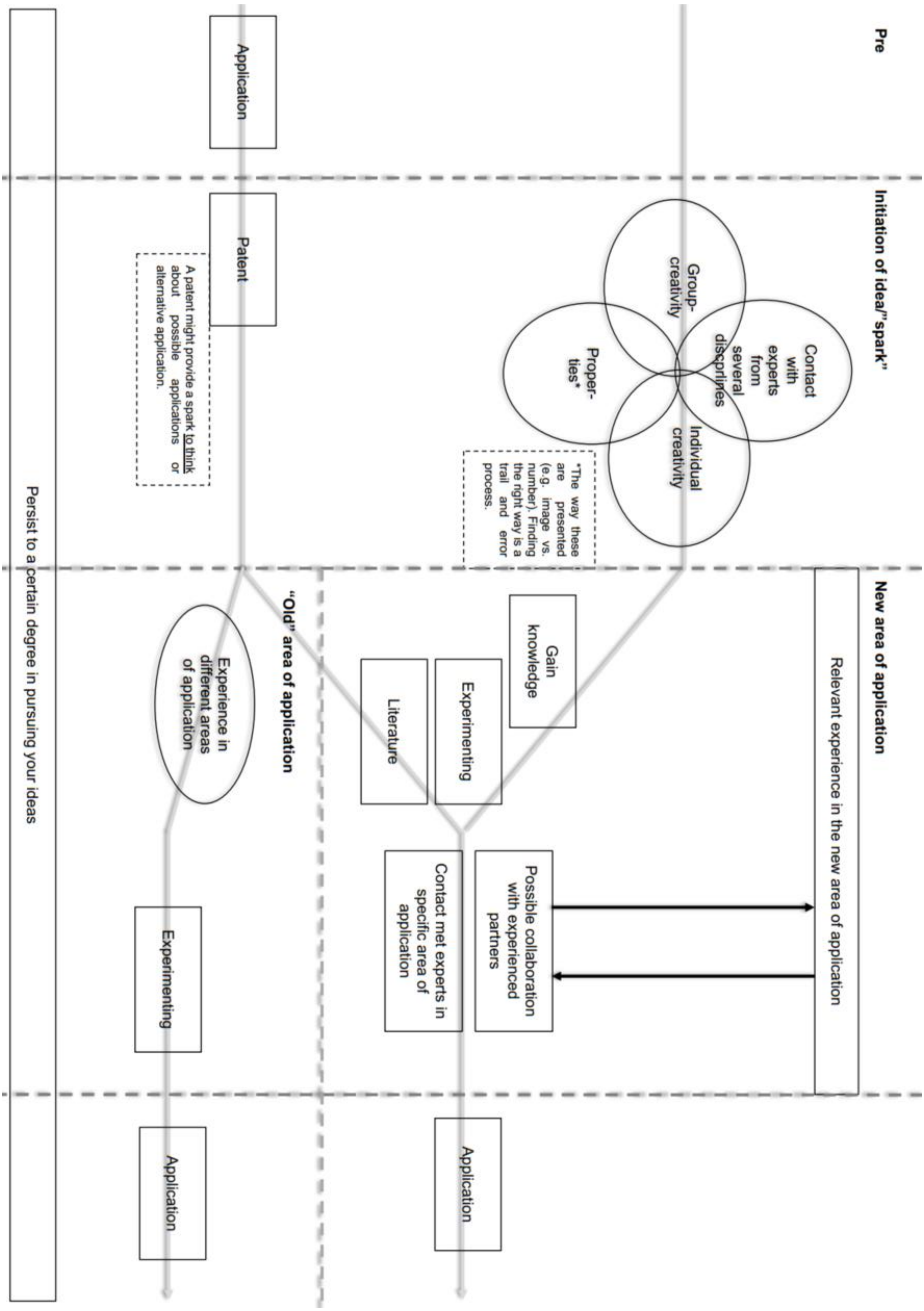
E.6 Framework I-051



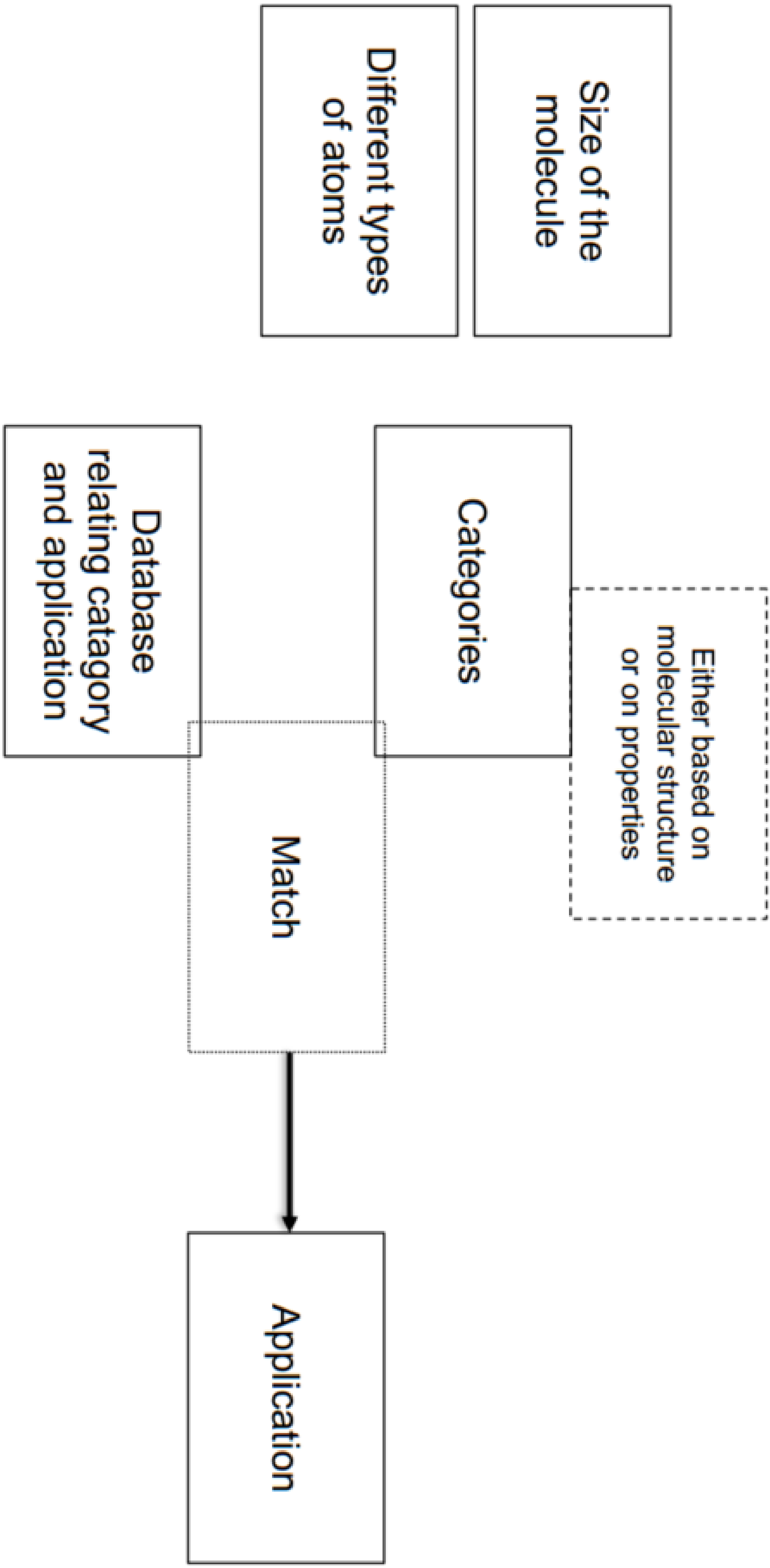
E.7 Framework I-060



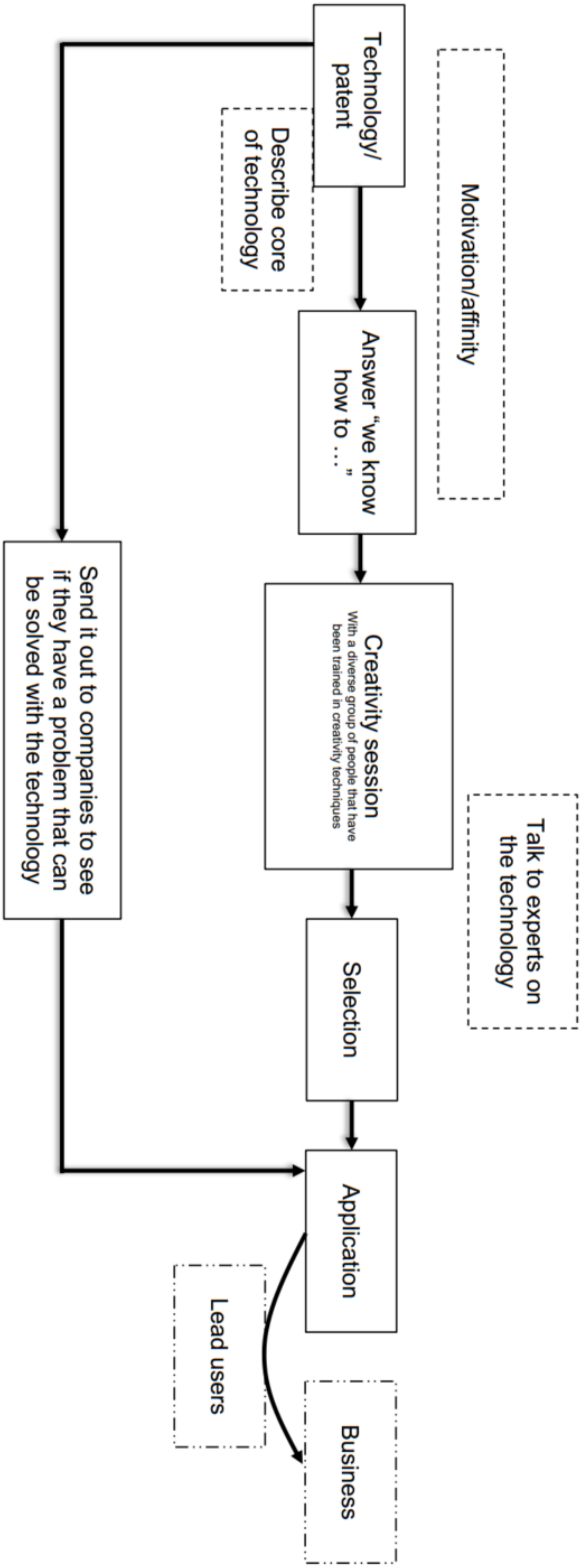
E.8 Framework I-070



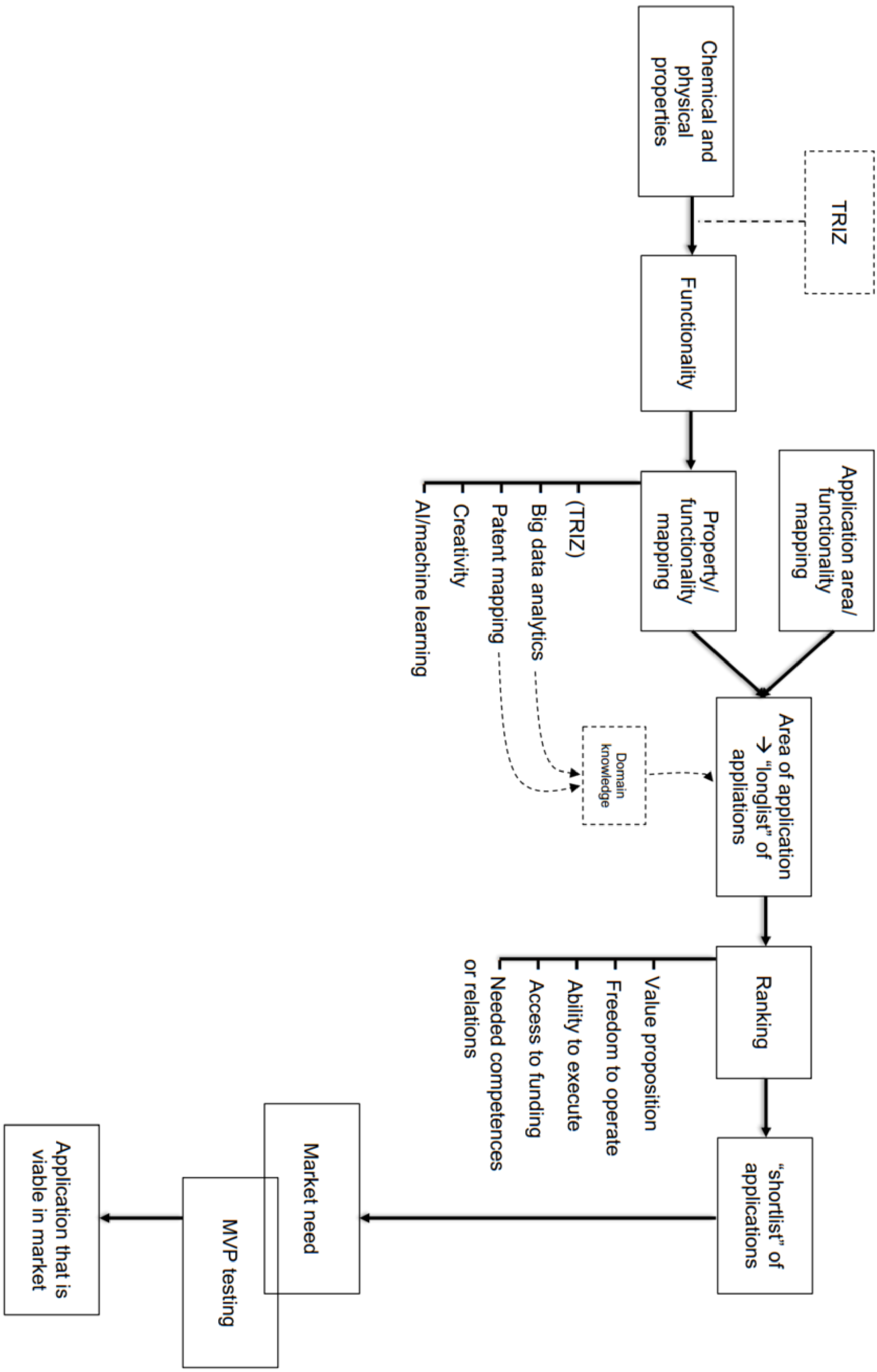
E.9 Framework I-080



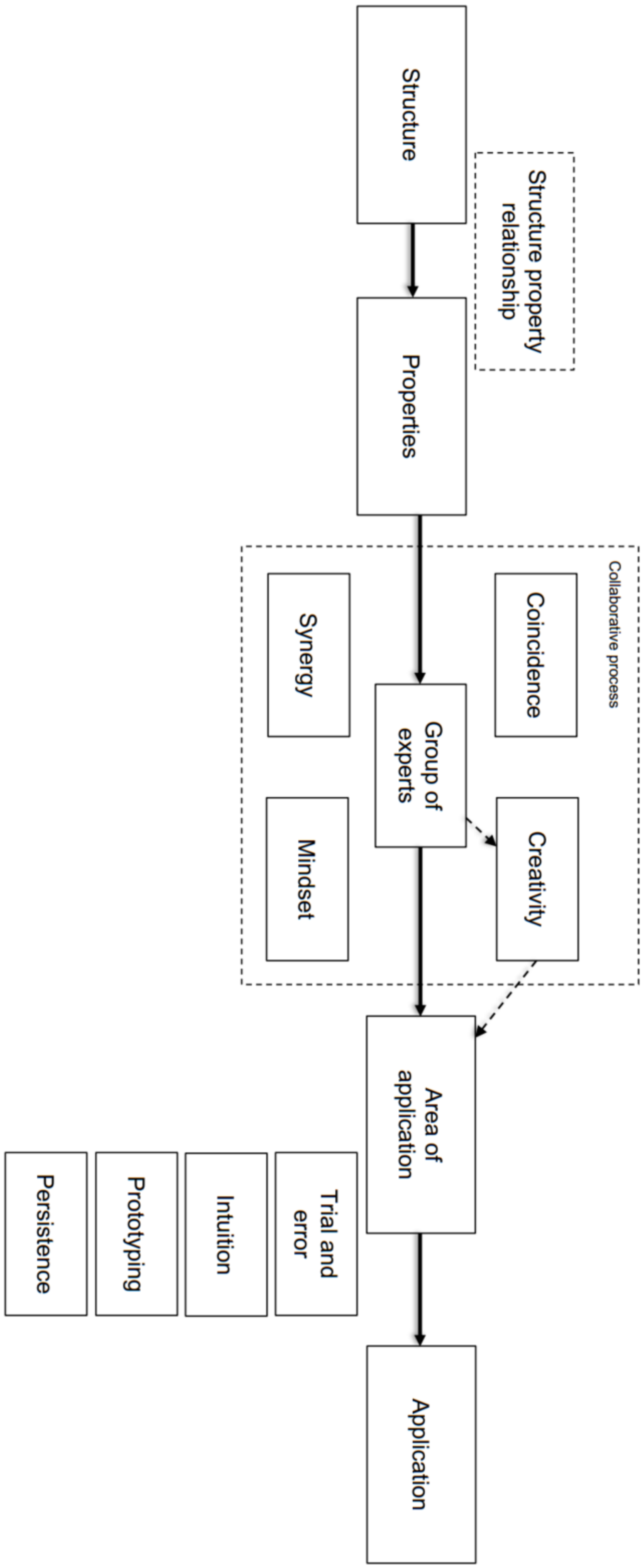
E.10 Framework I-090



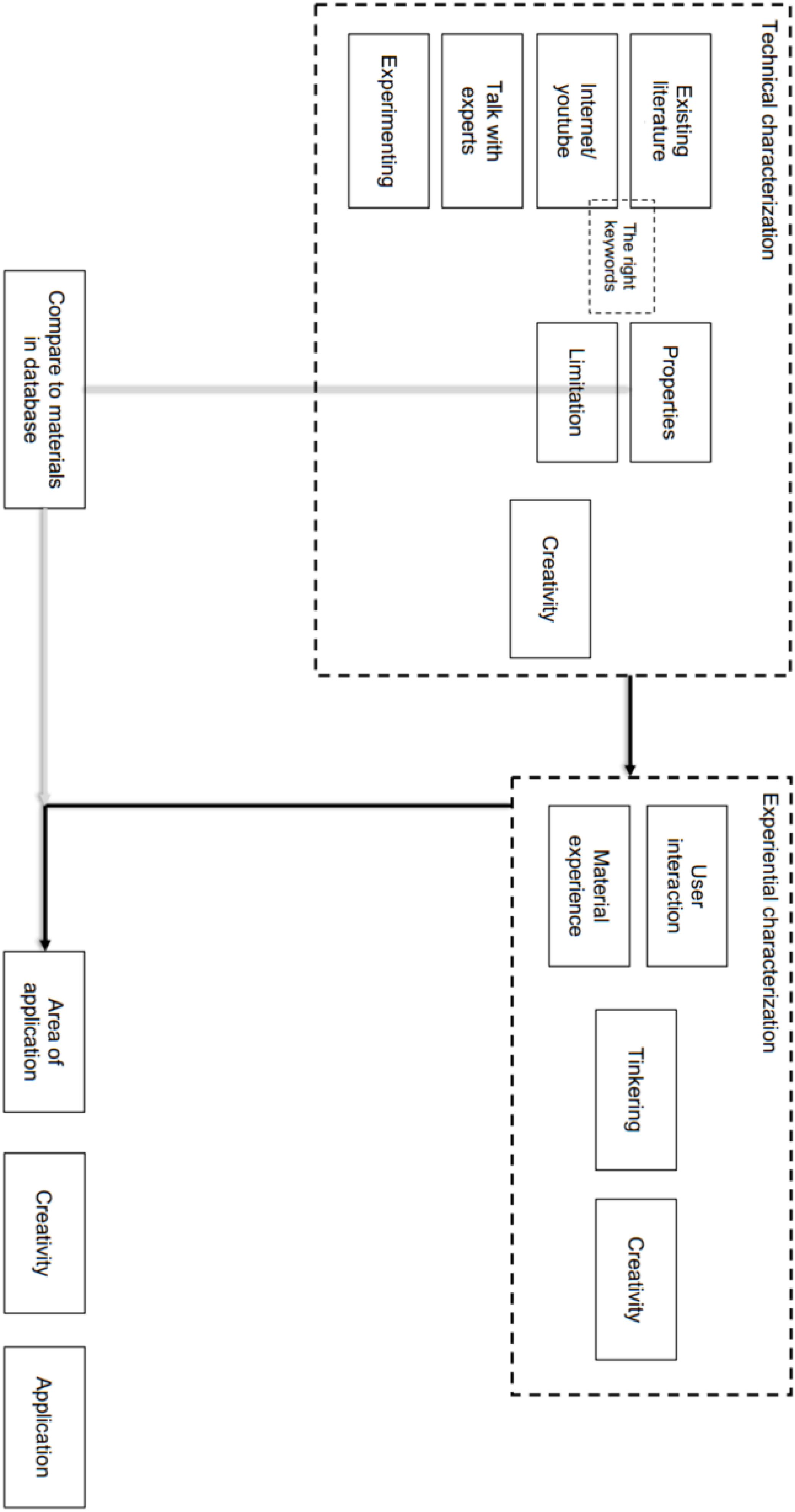
E.11 Framework I-100



E.12 Framework I-110



E.13 Framework I-120



Appendix F – Undiscussed elements from preliminary interviews

In chapter four, the results of the preliminary interviews were discussed. The elements that were left out of this chapter are discussed here.

F.1 Mindset

Firstly, the importance of mindset. This topic has been touched upon by several frameworks, albeit under different names. Framework I-070 calls it persistence, I-090 motivation/affinity, I-040 intentional search and I-010 challenging your ideals and wanting to make the world a better place. It is perceived that a certain state of mind is a common theme among these different aspects. It gives raise to the idea that someone who uses the framework to find applications has to have a certain inclination to innovate, both before and during the process.

Although not unimportant in the application generation or identification process, mindset will on itself not be included in the framework. It is believed the framework will inherently only be used by those who are motivated to find applications and thus already have the right mindset.

F.2 Functionality

For a definition of "functionality" the Cambridge online dictionary is consulted, where a functionality is defined as "the quality of being useful, practical, and right for the purpose for which something was made" [62]. Closely related to this are the concepts summarized as benefits: I-020 talks about advantages/disadvantages, I-050 talks about benefits and I-060 talks about favorable properties in an area of application.

Functionality and area of application are very similar. For this research, the concepts will be used as follows: an area of application can be defined only for the entirety of the technology under consideration. This technology has (several) functionalities it can perform, that can be benefits (or disadvantages) within a certain area of application.

Within an area of application, functionalities of a technology might be a good source of inspiration or information that can be used in the subsequent application generation, identification or matching.

F.3 Serendipity

Next, framework I-040 talks about serendipity, which is defined by the Cambridge online dictionary as "the fact of finding interesting or valuable things by chance" [62]. It can be applied in the context of finding applications by looking at several successful inventions from history: Velcro, Teflon, Nylon and Gore-Tex are but a few examples of the many inventions that happened "by accident", or with a high degree of serendipity to them [97, 98].

Albeit its importance in invention, it is difficult to incorporate serendipity into a framework, due to its nature. A framework aims to provide guidance and structure to a process, while serendipity is about chance. This does not mean the importance of *ad hoc* initiatives is not recognized. It is just not incorporated in the framework.

F.4 Forms of creativity

Creativity has been identified as part of the application generation process by several of the interviewees. On top of that, it has already been stated that it is no trivial matter. In framework I-040, different forms creativity are provided.

It is believed at this point that creativity will play a role in the final framework, as an essential part in the application generation process. How much information will be provided on creativity depends on the development process of the framework during this thesis.
The importance of creativity has been recognized, creativity will come back in this thesis, but maybe due to limitations (mostly in time) only in the "future research" section.

F.5 TRIZ

I-040, I-050 and I-100 mention TRIZ as a tool that might be used in the framework. Teoriya resheniya izobretatelskikh zadatch (TRIZ) which literally translates to "theory of solving inventive problems" (translated from Russian to English by Google translate) and is often named "theory of inventive problem solving" is exactly that, a method to systematically solve problems of invention [99].
The method is based on two essential thought: inventions are designed to overcome a technical contradiction and conflict arise due to the inconsistent development of individual components in technical systems [100].
Invention is described by the method as overcoming contradiction, by improving one aspect of a system without deteriorating other aspect. To overcome contradictions, the TRIZ methodology uses a system depicted in figure 10: the problem under consideration is abstracted to a generic problem (depicted in the figure as a TRIZ problem) by formulating it as a contradiction, using the 39 engineering parameters of the TRIZ methodology (found in table 15 in appendix J). Within this contradiction, one of the 39 engineering parameters has to better, without worsening the another. All possible combinations are gathered in a matrix. For each combination, the matrix offers a set of generic solutions (depicted in figure 10 as the TRIZ solution), chosen from the 40 inventive principles of the TRIZ methodology (found in table 16 in appendix J). The last step is to translate this solution into a specific solution of the original problem.
The above description of the TRIZ is by no means a full description or even a hands-on guide to using TRIZ. There are entire books written about TRIZ, so the description given is the bare minimum needed to understand the underlying principle of TRIZ (as best as understood by me at this time).
It is not expected that TRIZ will have a place in the final framework, since the method works from a problem-solving standpoint (application → technology) and not a "solutions searching for a problem" standpoint. However, an inversion of the TRIZ method might have a place in the framework. An inversion of the TRIZ methodology has been described in a paper, please refer to section 5.4 for more on this inverted TRIZ.

F.6 Trends

In I-010 and I-030, trends are mentioned as mechanisms with which (areas of) application(s) can be found. A trend is defined in the Cambridge online dictionary as "a general development or change in a situation or in the way that people are behaving" [62]. In this research, trends are mostly relevant when viewed from a technology perspective: if a technology or a product can further a general development or facilitate the change in situation or behavior, the technology can latch on to a trend to boost adoption of set technology.
When a trend is identified and followed, an area of application is identified. Area of application has been previously defined as "purpose" (see section 4.2.3). When following the same example provided for area of application, with the car catalyst, a potential trend can be to improve car catalysts. Now when this trend has been identified, the area of application of catalysis is also identified.

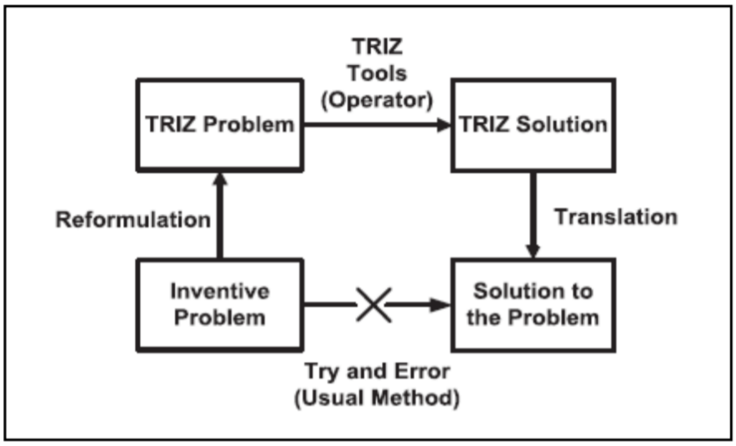


Figure 28: TRIZ methodology, from [5].

F.7 Patent sending

Lastly, in I-090, the idea is proposed to find applications for technologies by sending out patents to companies and letting companies find/create applications for the described technology. Whether this method might work is unknown, but the method does not seem to be within the scope of this research, since the scope of this research is developing a framework to assist in this application identification or generation process.

Since this method has not been mentioned outside of this single interview, it is believed there is not a solid basis on which to include it in the framework. It will be mentioned in the future research section.

Appendix G - Frameworks from literature

G.1 Technology-utilization-model (TUM)

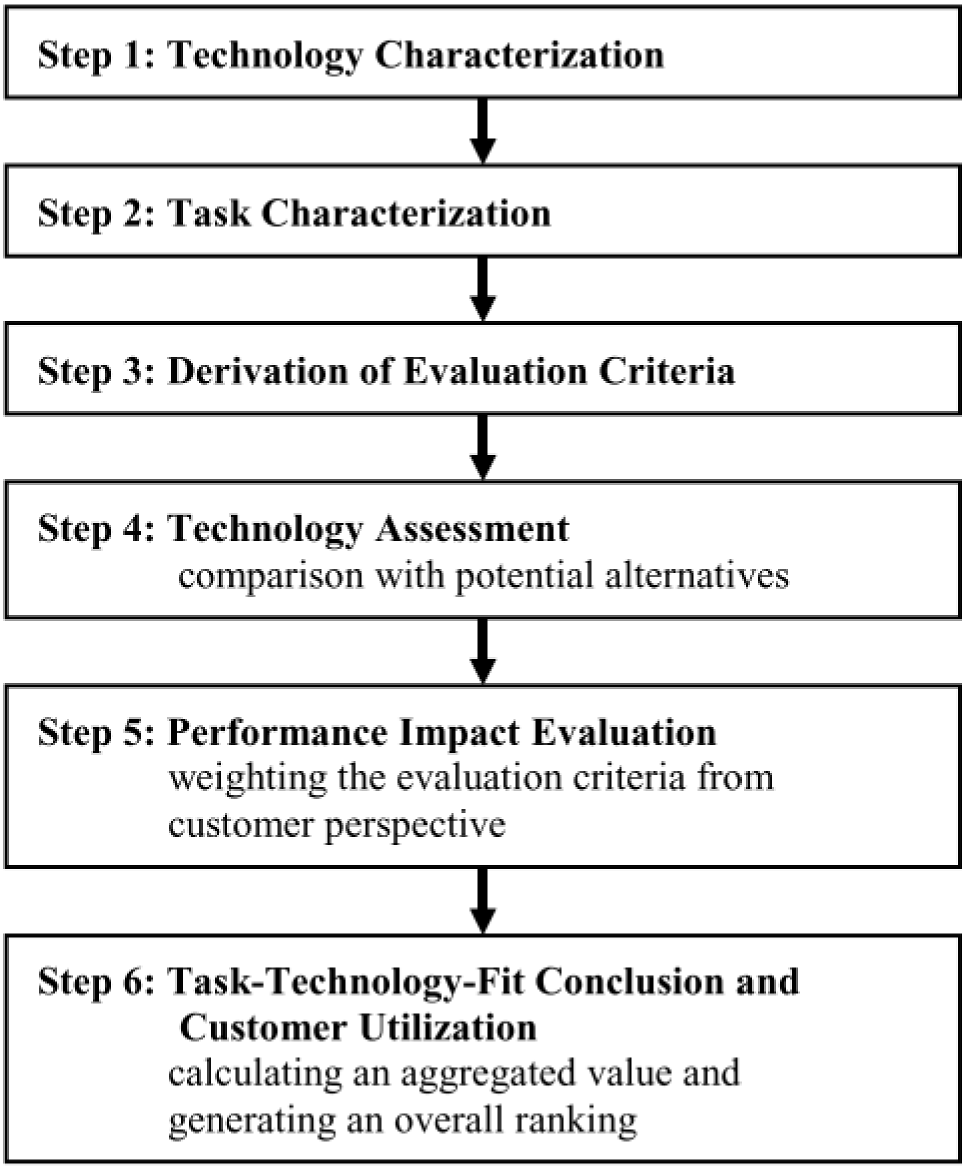


Figure 29: Technology-utilization-model (TUM) from [8].

G.2 Technology-push lead user concept (T-PLUC)

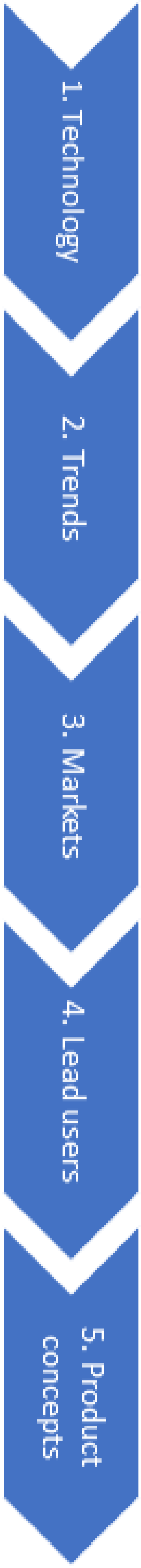


Figure 30: Technology-push lead user concept, adapted from [14]

G.3 Total system approach to technology push (TSA)

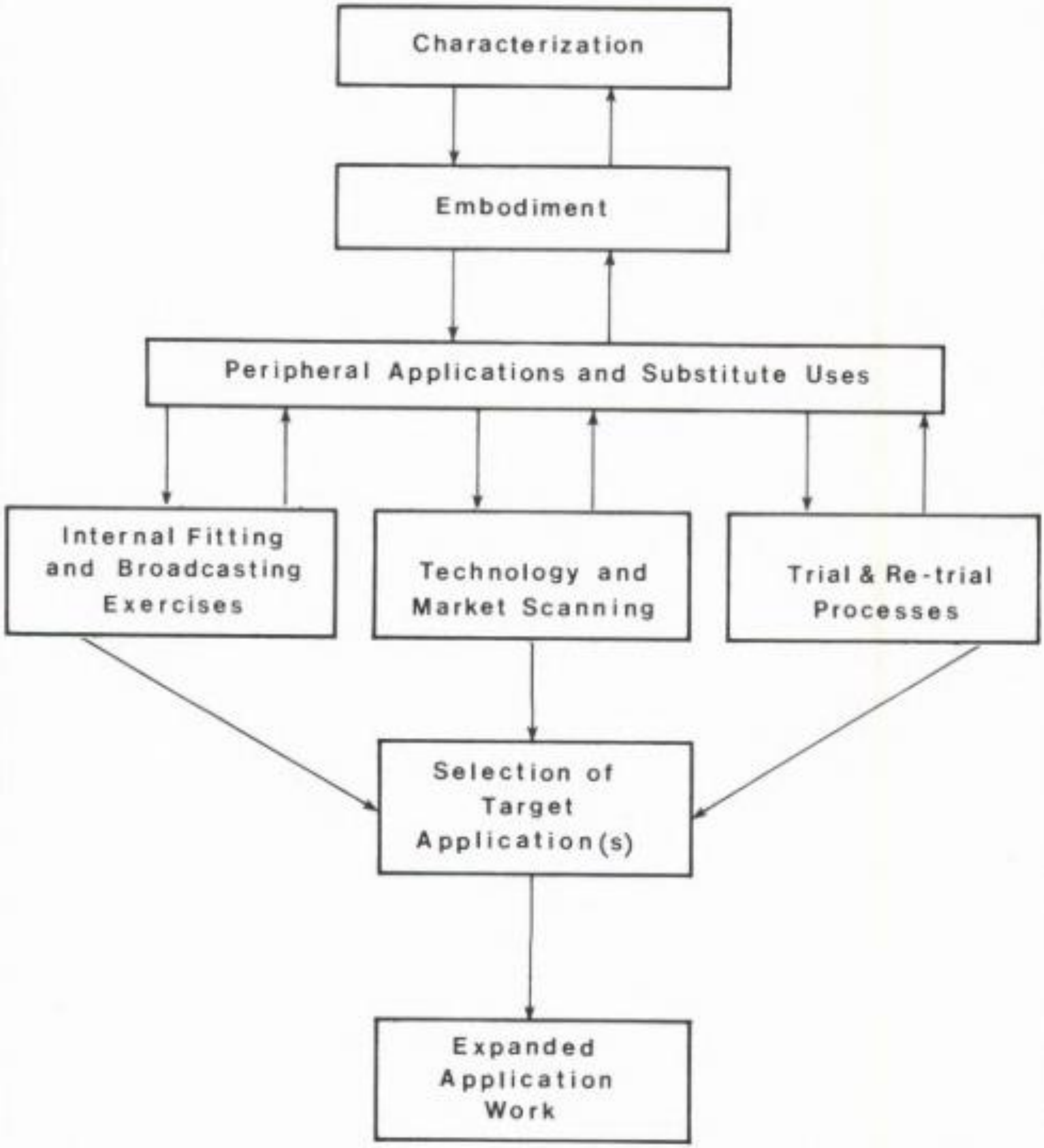


Figure 31: Total system approach to technology push, from [20].

G.4 Method for the identification of alternative technology applications (ATA)

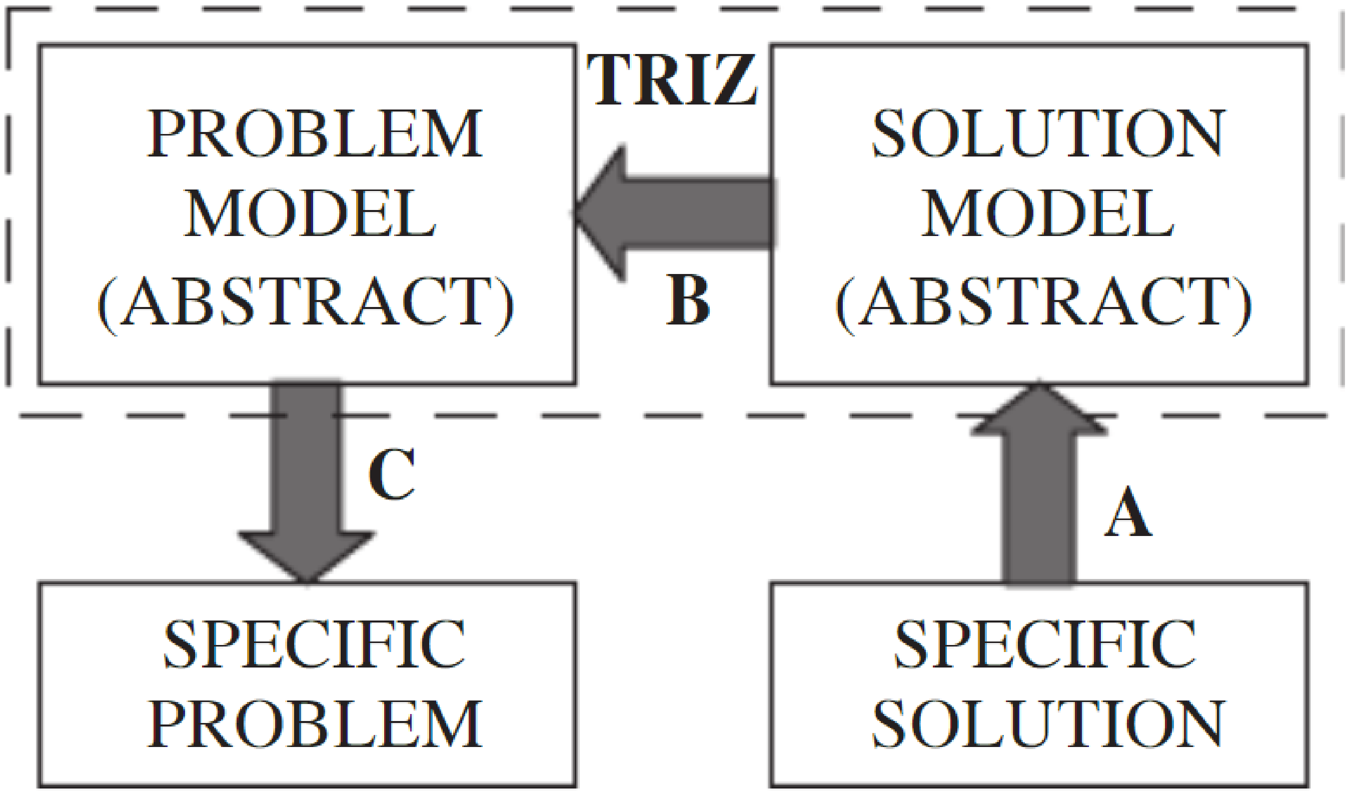


Figure 33: Inversion of TRIZ, from [47]..

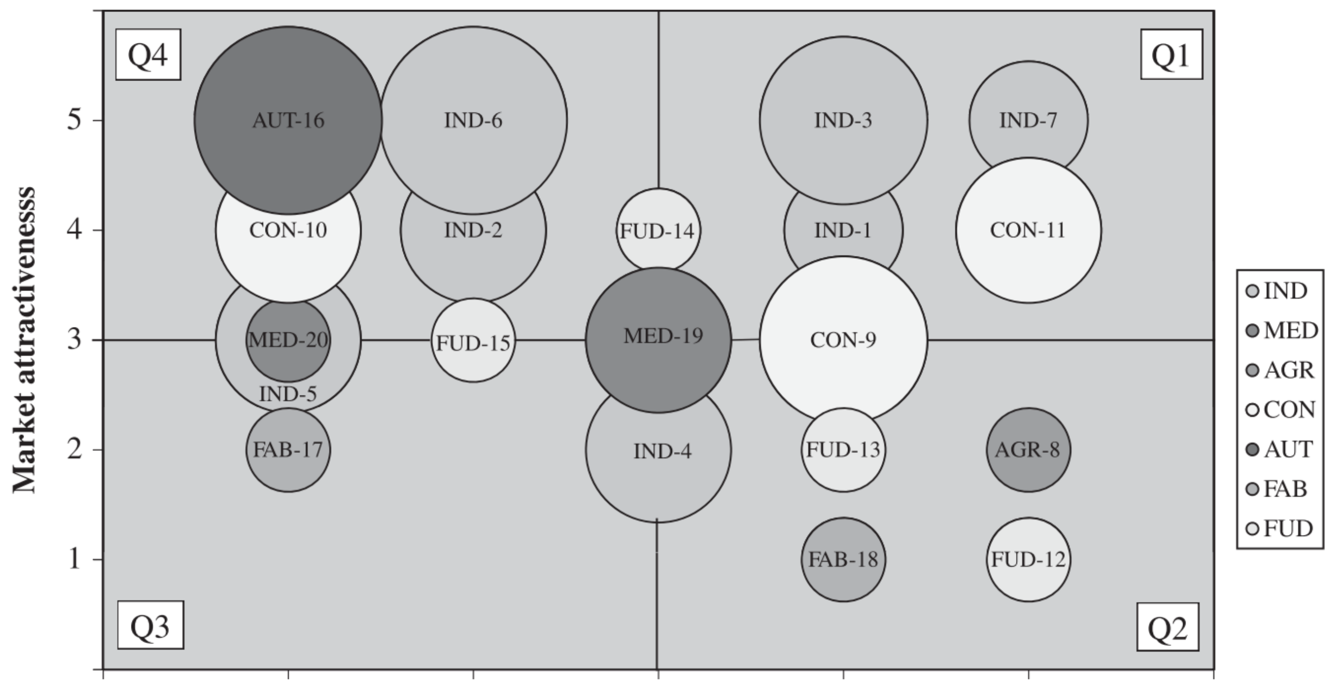
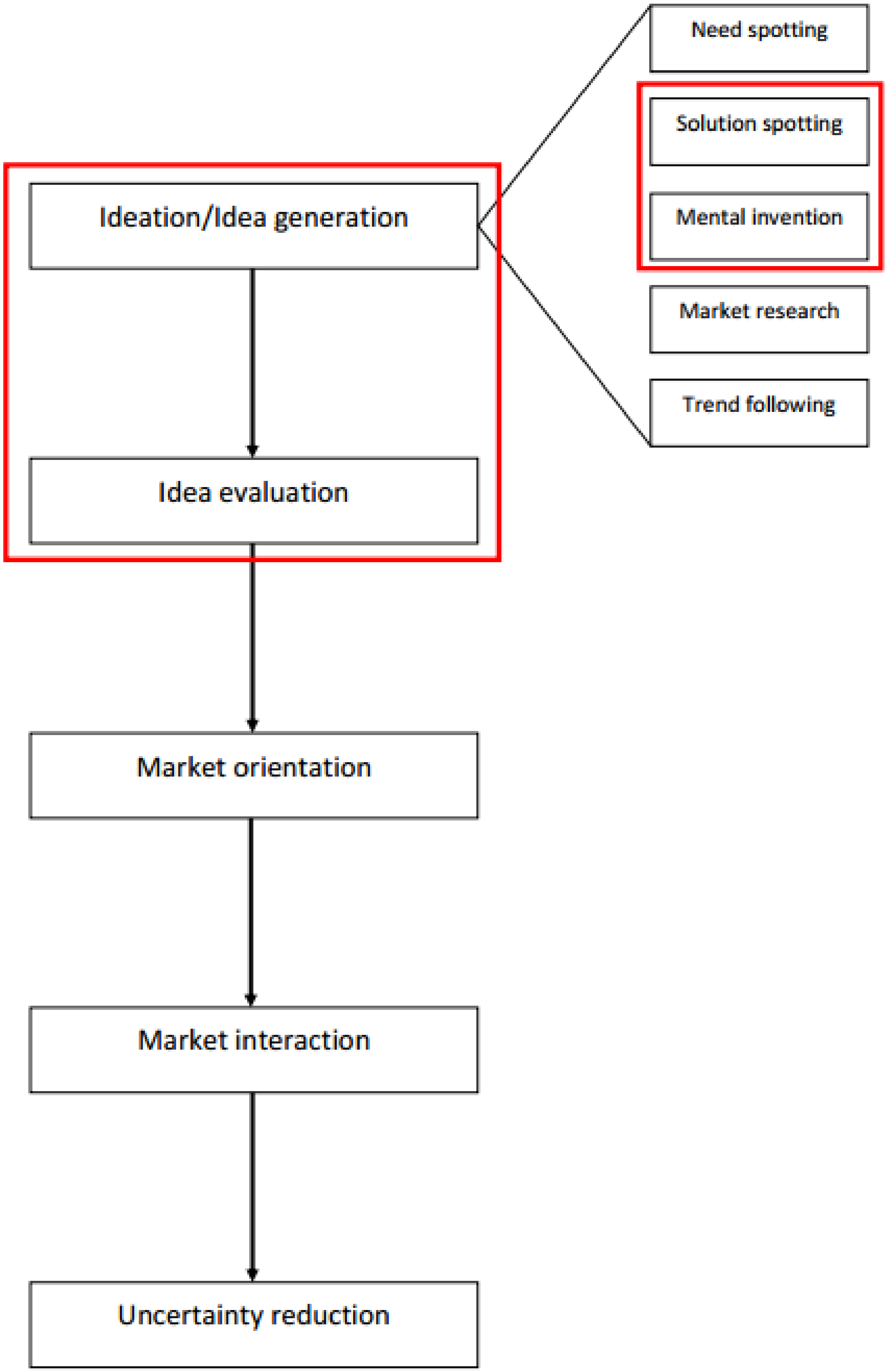


Figure 32: Result of the method to find alternative technology applications, from [47].

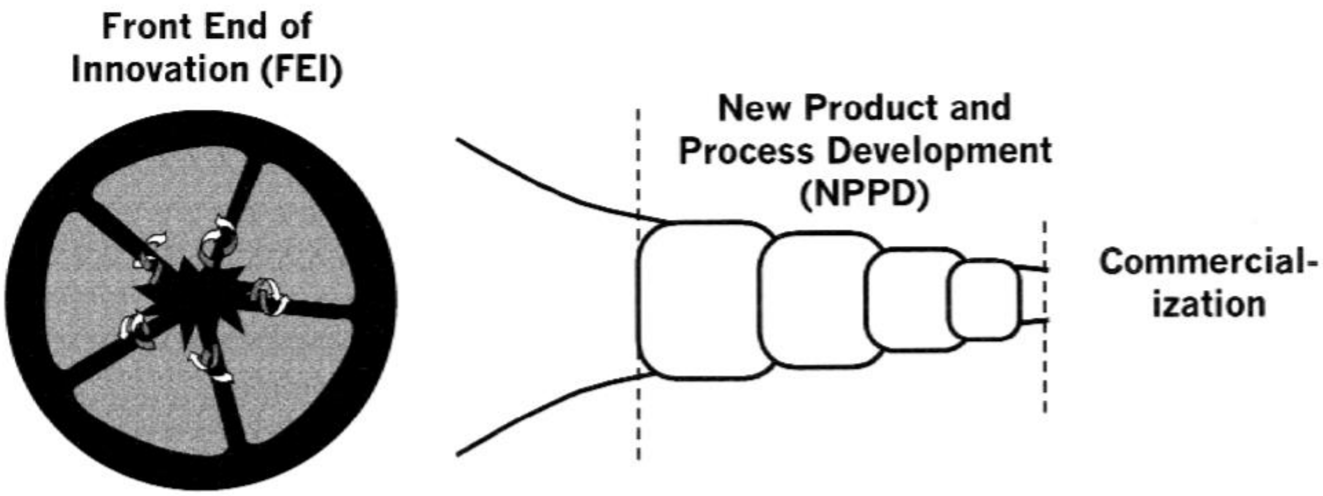
Function	Score	Function	Score
To Absorb	Maximum	To Freeze/Boil	Low
To Accumulate	Medium	To Heat	Medium
To Assemble	Medium	To Hold	High
To Bend	Maximum	To Join	Low
To Break down	Low	To Locate	Medium
To Change phase of melts	Low	To Mix	Medium
To Clean	Low	To Move	Medium
To Cool	Low	To Orient	Medium
To Corrode	Low	To Polish	Low
To Decompose	Low	To Preserve	Maximum
To Deposit	Medium	To Prevent	High
To Destroy	Low	To Produce	Low
To Detect	Medium	To Protect	Maximum
To Dry	Low	To Remove	Low
To Embed	Low	To Rotate	Low
To Erode	Low	To Separate	Low
To Evaporate	Low	To Stabilize	High
To Extract	Low	To Vibrate	Low

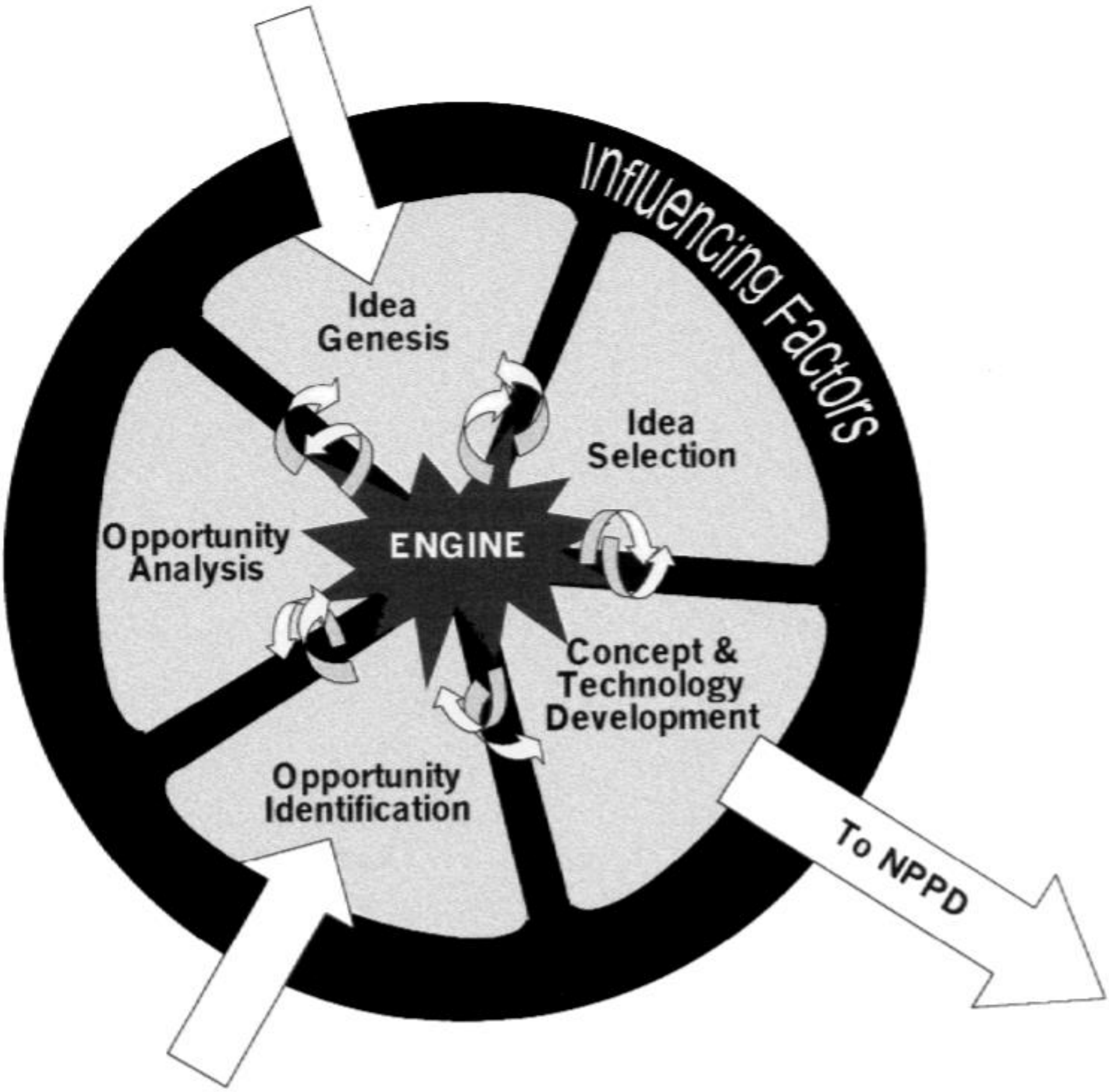
Trend of evolution	Stages of development	PACK TECH stage	Trend of evolution	Stages of development	PACK TECH stage	Trend of evolution	Stages of development	PACK TECH stage	Trend of evolution	Stages of development	PACK TECH stage
Action coordination	1. Non-coordinated action 2. Partially coordinated action 3. Coordinated action 4. Action with intervals	1	Mono-bi-poly-similar objects	1. Mono-system 2. Bi-system 3. Tri-system 4. Poly-system	2	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 energy conversion n to 0	1. Several energy conversions 2. Reduced energy conversions 3. One energy conversion 4. No energy conversion	2
Rhythm coordination	1. Continuous action 2. Pulsating actions 3. Pulsating action in the resonance mode 4. Travelling wave	1	Mono-bi-poly-various objects	1. Mono-system 2. Bi-system 3. Tri-system 4. Poly-system	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 4. IFR	2	Controll-ability	1. Direct control 2. Control through intermediary 3. Addition of feedback 4. Addition of intelligent feedback	1
Geometric evolution of linear constructions	1. Point 2. Line 3. 2D curve 4. Axi-symmetric 5. 3D curve	3	Space segmentation	1. Monolithic 2. Hollow 3. Multi-holed 4. Capillary porous 5. Porous with active elements	3	Geometric evolution of volumetric constructions	1. Plane 2. 2D curve 3. Axi-symmetric 4. 3D curve 5. Fully 3D	2	Market evolution	1. Commodity 2. Product 3. Service 4. Experience 5. Transformation	2
Mono-bi-poly-increasing differences	1. Similar components 2. Components with biased characteristics plus negative component 4. Different components	1	Degrees of freedom	1. Single degree of freedom system 2. Second degree of freedom system freedom system 4. Fourth (or higher) degree of freedom system	1	Customer purchase focus	1. Performance 2. Reliability 3. Convenience 4. Price	1	Webs and fibers	1. Homogeneous sheet 2. 2D regular mesh structure aligned according to load conditions 4. Active elements	2
Increasing use of color	1. No use of color 2. Binary use of color 3. Use of visible spectrum 4. Full spectrum use	3	Reduced damping	1. Heavy damping 2. Critical damping 3. Light damping 4. Undamped	2	Boundary breakdown	1. Many boundaries 2. Reduced boundaries 3. Few boundaries 4. No boundaries	3	Increasing transparency	1. Opaque 2. Partially transparent 3. Transparent 4. Active transparent elements	1
Dynamization	1. Immobile 2. Single joint 3. Multiple joints 4. Completely flexible 5. Liquid/gas 6. Field	3	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	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	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 asymmetry	1. Symmetrical system 2. Partial asymmetry 3. Matched asymmetry	1	Non-linearity	1. Linear assumption of the system 2. Partial accommodation of system non-linearities 3. Full accommodation of system non-linearities	1	Smart materials	1. Passive material 2. One-way adaptive 3. 2-way adaptive material 4. Fully-adaptive material	1	Increasing use of senses	1. 1 sense 2. 2 sense 3. 3 sense 4. 4 sense 5. 5 sense	1
Decreasing density	Scale from 10^4 to $10^{-3}\ kg/m^3$	$10\ kg/m^3$	Macro- to nanoscale	Scale from 10^2 to 10^{-9} m	10^{-1} m						

G.5 Normative model for idea generation and opportunity recognition (NGR)



G.6 The new concept development model (NCD)





Appendix H – technology description framework

As briefly mentioned before, in the paper by Linton and Walsh [55] a framework for technology description is developed, based on a framework for "analyzing individual artifacts" by Van Wyk [101]. The framework consists of five questions one has to answer for a given technology:

Function: what does it do? According to Linton and Walsh, a technology can always be described with one of three verbs plus one of three nouns. The verbs are process, transport and store, the nouns are matter, energy and information.

Performance: how well does it do it? Or rather, how well does a technology perform its given function. There are four characteristics that are important in describing most technologies:

- Efficiency: output obtained per unit of input.
- Capacity: this characteristic depends on the verb used in the function description. For process, capacity is throughput, for transport, capacity is distance traveled per unit of time and for store, capacity is amount stored per unit of mass or unit of volume.
- Density: output obtained per unit of space occupied.
- Precision: measure of clarity or exactness.

N.B. it is possible that a certain technology has characteristics that are different and relevant. If so, these characteristics should be mentioned.

Structure: how is it configured? A description of the technology in terms of shape, size and complexity. From these three, complexity has been identified by De Wet [102] as being the most important. Complexity describes how a technology fits in with other elements and can be described with one of four terms: material, component, product or system, each with a higher complexity. At the simplest level of complexity, a technology can be a material. When the technology becomes slightly more complex, it can be a component in an existing product. Again, more complex, a technology can be a new product made from existing materials, but with a novel configuration that delivers new or improved benefits. Lastly, in the most complex form, a technology can be a system, a set of products used together to provide new or improved benefits.

Size: how big is it? Literally the physical dimensions of a technology.

Material: what is it made of? The materials embedded in the technology are stated. These materials are important, since it implies certain properties and manufacturing techniques. The recommended classifications are metals, polymers, ceramics, glasses and composites. Some materials exhibit out-of-the-ordinary properties, but this has usually been stated under the performance aspect already.

Whether this technology description model will be used in the framework developed in this thesis remains to be seen. However, the concept of this framework raises the idea that it might prove useful to identify some sort of format in which technologies are presented, to improve usability of the technology description.

The model described above provides a very concise and structured approach to technology definition. A downside of such an approach might be that the technology description remains to broad to inspire or yield innovation. For example, when you define the function of a laser as "transports energy", the step to identify the application of eye lasering surgery is still very far away. However, if one defines the function a laser technology as "cut matter", the eye lasering surgery is suddenly a lot closer.

Appendix I – Interview reports second series

I.1 Interview ir. P. Vercoulen (candidate 11)

N.B. the interview was held in Dutch and thus has been translated. On top of that, this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

What do you think of the framework thus far?

The framework as it is now is so generic that it can fit onto any form of development. If you want to make anything useful out of it, you have to make it more specific (less broad and deeper).

Any idea how to approach this creating a less broad and deeper framework?

In our previous interview you talked about how you wanted to make the framework for organic molecules. I think this is still a very generic origin. I would pick a specific area of application and work out the framework for that specific area of application. On top of that, you could do this for a second (related) area of application and compare the two processes/outcomes with each other.

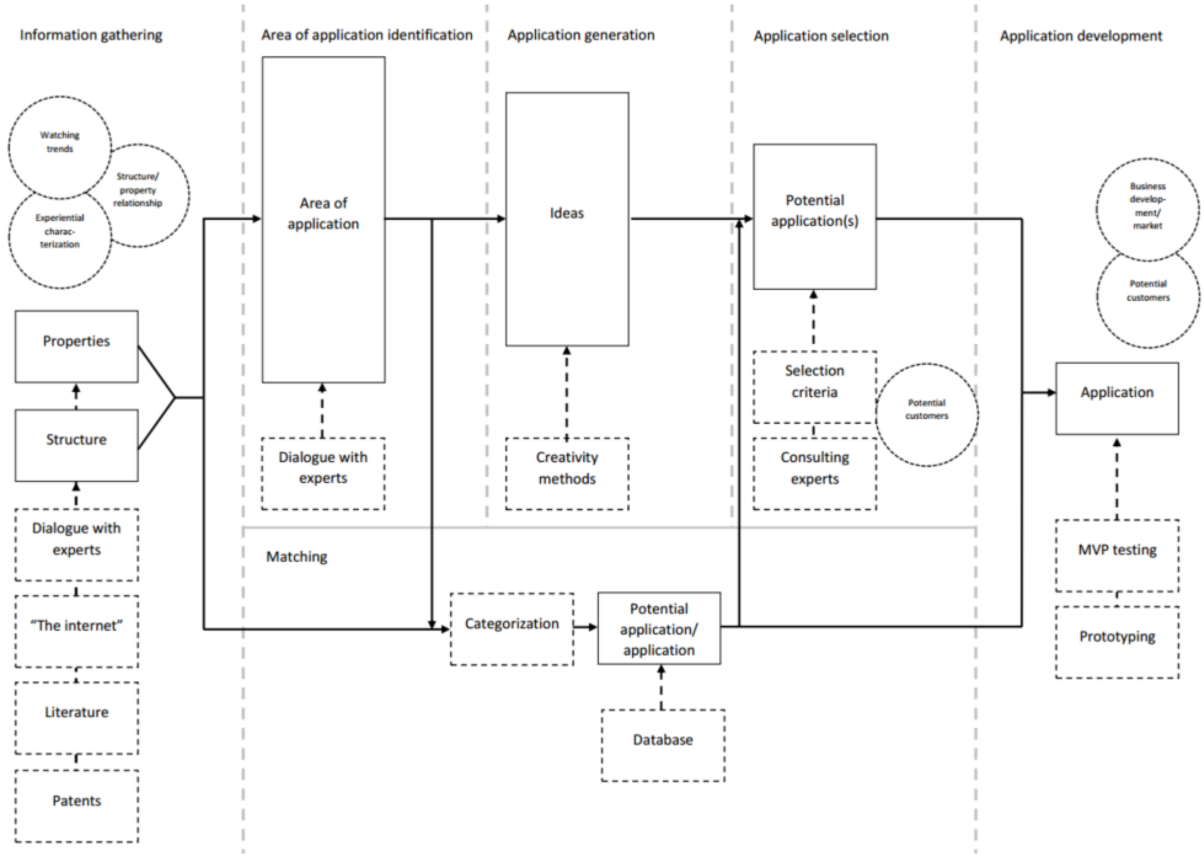
Is there anything you would change in this framework?

I would add a clear start and ending. What I am missing from your current framework is a starting point, for example a technology or an organic molecule.
But again, this framework is very generic, it will fit for everything. It does not provide anything new to the world. The question you have to ask yourself is what you want to provide with this framework, what is the added value.

How would you approach the specification of this framework in the direction of organic molecules?

I would think about the functionality of the molecules and of their value (for example, a very expensive molecule has to pay back the investment/OPEX, or it won't fly). Other than that, I find it very difficult to answer that question, since the framework is so generic.

The framework that was sent to Paul is depicted below:



I.2 Interview prof. dr. S.J. Picken (candidate 9)

N.B. the interview was held in Dutch and thus has been translated. On top of that, this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

A first remark by Stephen was that there is no clear starting point indicated in the framework. It should be clear that the starting point for the framework is an organic molecule that you already have.

How would you approach the first steps of finding applications specifically for organic molecules?

Well, looking at the frameworks, the methods you provide to gather information (dialogue with experts, …, patents) imply that there already is an area of application for the molecule you are considering. You can't randomly search for patents filled for some molecule.
The methods are linked to the application selection. In practice you often directly think for a molecule "this might be adequate for this and this application", so a selection of those potential applications takes place and from there you might think of other potential applications (via analogy for example). It might be the case that later on in the process you find that the first application(s) you thought of were not that adequate, but they led you to better applications.

In summary, I doubt the process is always as structured and funnelled as you describe it. The process might have a different order, might be iterative or even cyclic.
And apart from that, sometimes you define applications for a certain technology/material, but the applications that in the end turns out to be the most profitable turns out to be something totally different. Often these profitable applications are identified by accident.

I believe it is essential to go through a application generation or identification framework several times. Each time you might look at different properties and identify different potential (areas of) application(s).

Okay, lets take one step back from here. Say I have a flask with some compound in it, and I want to find an application for this compound, how would I approach this?

I would start with the characteristics of the molecule on a meta level. For example, organic molecules always contain C and H, and some contain O, N and S. The number of molecules you can create with these elements is enormous, but there is a certain structure, which we call organic chemistry. Any organic chemistry book might provide a structure in this matter.

Functional groups might be a way to structure organic molecules (alcohol, ketone, ester, sugar, amines, organo-metallics, nitrates, …). **Maybe something to consider here is an analysis or categorization of organic molecules on four different levels, comparable to the 4 different types of structures in proteins.** Difference between aromatic and aliphatic. Polarity or even amphiphilicity.

Molecular weight also plays a role, polarity and the two combined: phase change points/state.

Price is a good selection mechanism; some synthesis prices or price ranges will inherently exclude certain areas of application.

A first summary of potential areas of application: something with a lot of unsaturated bonds will probably have sensitivity to light, a small alcohol will probably be a good fit for solvent applications, something toxic will not fit for food/cosmetics/DIY/consumer product applications.
However, toxicity might be a good fit for medicine, agriculture (pest control) applications, depending on the degree and type of toxicity.
Amphiphilic compounds might be a good fit with for the surfactants market, or paint/primer market.

I see two different types of categorization we are making here, based on structure and based on functionality.

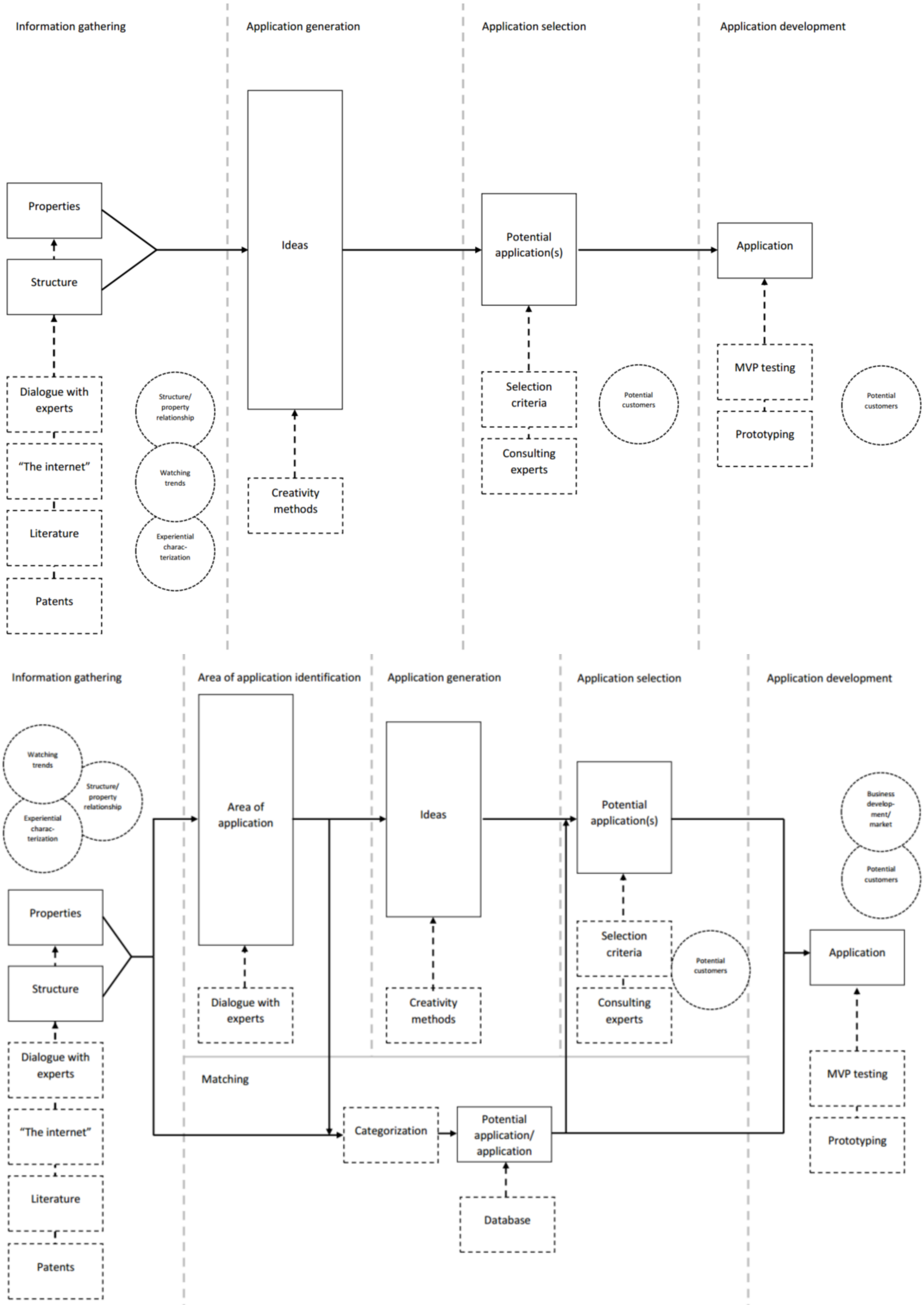
Well, they are two side of the same medal. You might view this as a matrix, where one direction is the different classes of organic molecules based on structure and the other are the properties of the molecule (coloured or not, melting point, boiling point, polarity, symmetry, sensitive to light, molecular weight, branched, etc.).

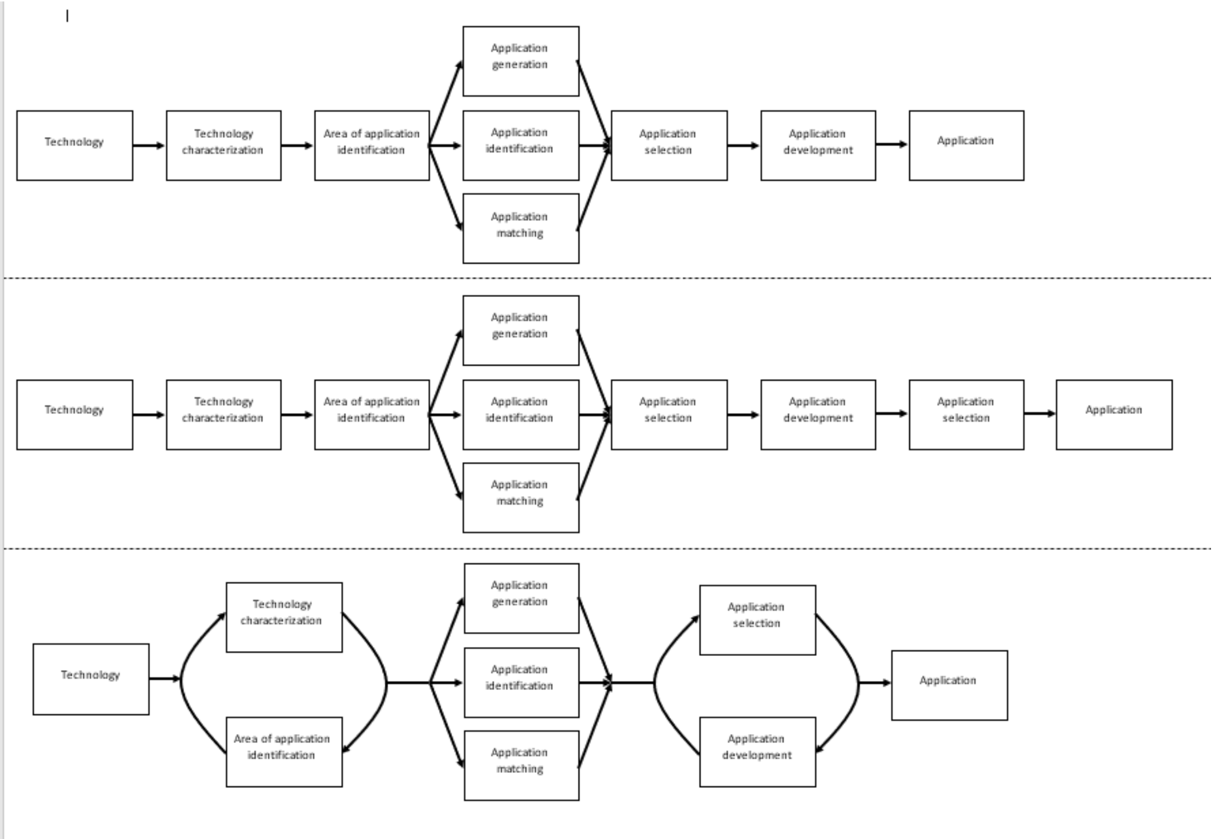
Let again take a step back to the framework I am creating. Could it be an idea to list all possible areas of application for organic molecules and look at critical properties for each area of application?

Well, in theory that should be possible. You should keep in mind that some properties are needed in multiple areas of application.

Another level on which you might look at this idea is that an organic molecule has a function and this function only exists through interaction with the surroundings. There are a couple of different fundamental interactions: temperature, surface/interfacial effects, electrical effects, light effects, magnetic effects, electromagnetic effect, mechanical and rheological properties, interaction with life.

The frameworks that were sent to Stephen are depicted below:




Technology
Technology characterization
Area of application identification
Application generation
Application identification
Application matching
Application selection
Application development
Application
Technology
Technology characterization
Area of application identification
Application generation
Application identification
Application matching
Application selection
Application development
Application selection
Application
Technology
Technology characterization
Area of application identification
Application generation
Application identification
Application matching
Application selection
Application development
Application

I.3 Interview dr. R.F.P. Grimbergen (candidate 13)

N.B. the interview was held in Dutch and thus has been translated. On top of that, this is not a transcript, but an interpretation. The *cursive* text are questions asked by the interviewer, the normal text is answers by the interviewee. The **bold** text are notes for the interviewer.

[explaining the framework as it is now] …but I do need to change the name of the "application development" to something less rigorous. It is really only a step in which you give every conceived idea some love and attention before you do selection.

I would say you can name it "application validation", I think in that step you look at whether there is a match between technology and application.

What do you think of the framework as presented?

I do recognize the general flow of the framework. Now you want to make it specific for chemistry. By chance, I had a discussion yesterday with a start-up in chemistry about what to do with the molecule they created. In this first meeting, there is an interactive discussion in which the company provide characteristics of the molecule and I provide potential areas of application, based on my own experience.
When a potential area of application has been identified, it is important to identify specific characteristics needed within this area of application and from there see whether the molecule proposed has these characteristics.

This sounds like moving from tech-push to market-pull: when an area of application has been found, you are trying to describe the problems/challenges there are in this area of application and you try to see whether the molecule you propose could address these challenges.

Yes, you go through the "pain chain", looking at where the current challenges in a certain market are at the moment. In this phase, you could answer questions like "in an ideal world, what should a solution to your problem be able to do?".
Apart from that, it is important to compare the molecule you are proposing for a certain application to other molecules in this application. You need to be significantly better or significantly cheaper than the current solution.

Let's take a step back from here, can we define a minimum set of characteristics we need to start the area of application identification process?

Well, coming back to what I said in the previous interview, you need experts for this. People that have worked in a certain field for several years, who know what is going on in the market, who know suppliers, you know clients, etc.

If we were to apply that, we would have to define the different areas of application that exist for organic molecules, find experts in all these areas and place them together in a group/thinktank situation to create an application generation machine?

Yes, that might in theory work. They will surely ask you questions, about REACh registration, supply chain, OPEX, CAPEX, toxicity profile, chemical properties, structure.

Starting from that idea, what would be a minimum set of characteristics that we should feed to this thinktank?

We can structure the mentioned characteristics into four categories: regulatory/toxicity, chemical/physical properties, financial, structure.
For the chemical/physical properties you might want to look at a website of a chemical supplier at a technical detail sheet. The info they provide on this sheet might be a good starting point.

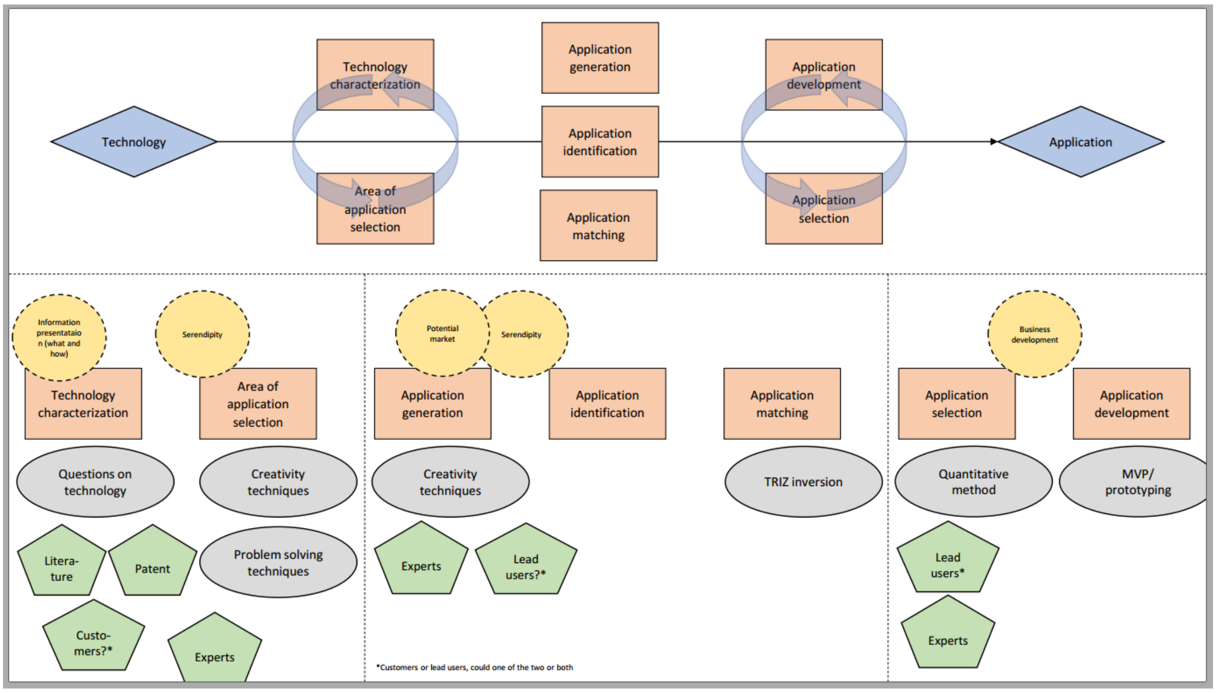
There is starting to form this idea in my head where in theory you could identify all areas of application available in organic chemistry and subsequently identify characteristics needed to be applicable in these areas of application. It his something you think that could work?

Yes, I think this could work.

Do you have any idea how to find the areas of application for organic chemistry?

Yes, I will email you two websites where you can make a start with this:
https://cefic.org/
https://chemistrynl.com/themes/

The framework that was sent to Reinier is depicted below:



I.4 Interview dr. ir. G.M.H. Meesters (candidate 7)

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Looking at your framework and listening to the explanation, it does sound like you perceive the process as if everything happens within one company. This could be the case, but this is definitely not always the case. **This is also a question of where the framework ends.**
I just talked to Stephen Picken; we are currently developing an application for a polymer product that can glue leather. Before any development is done, a demonstrator is made, the simplest product that shows the function of the molecule/the technology. On top of that, after the workings of the technology have been shown, there also needs to be marketing (market development) → finding clients who want to develop your technology further. Here you move into the stage gate model. **Look at stage gate model. On top of that, maybe remove development altogether, since this is a whole different science (design science?)?**

In general, this process is the depicted right by your framework.

I can relate to the idea of incorporating market development early on in this process. I also found this in a piece of research, where the authors of the paper propose to include clients already at the identification of areas of application. However, I think it is very difficult to include clients from a market when you do not know in which market you will navigate your product.

Well, some ideas are developed starting from a technology, but the majority of the ideas are engineered based on a problem in the market. Following the example of the crystal-clear beer and the enzyme solution. However, from the solution (the enzyme) we proposed, a new market was reached, because the same enzymes also destroyed the gluten in the beer, making the beer drinkable for people with a gluten free diet.

Now we discussed the framework in general, I would like to make the step to specificity. In the last phase of my research, I want to replace the word "technology" with "organic molecule". So, we have an organic molecule in hand, how do we find applications for that?

Well, I just mentioned Stephen Picken. He is working on a bioplastic, which is a substance they more or less found by accident. After they discover it, they had a brainstorm for potential applications and when they found some, they quickly went into a prototyping phase. Here you make a demonstrator to prove that the molecule and the application are indeed a fit. Here you show the market what you can do with your technology and after that you move into development, scale, etc.

The picture you paint fits very nicely with my framework. Zooming in on the first steps, before the brainstorm, what would be a minimum set of information you need to feed into the brainstorm?

Well, you almost never randomly throw things together, so you have some idea in which category you are operating. After determining structure and properties, you need experts to generate potential applications.

These categories are what I am looking for. We already had the example of plastics, but what would be others?

On the largest level, we have organic and inorganic molecules. Within the organic molecules, you can subsequently look at functional groups on your molecule and determine which functional groups are often found in certain areas of application.
There should be literature that relates functional groups to aera's of application, but I would not know any books/paper from the top of my head.
It will become more complicated if you have several functional groups within the same molecule. There you need to consider which functional groups play a more important role and which a less important role.

I could see a development process of a database in which functional groups and functionalities are coupled. These developments would be an iterative process in which more and more complex molecules/structures would be embedded, taking into account the amount of expression a functional group gets within the total characteristics of a molecule.

I could link you up with people from DSM and there you can test your framework.

That is a very nice opportunity, but I need to deliver a first draft in 2 weeks. **This is something that could be a future master thesis project.**

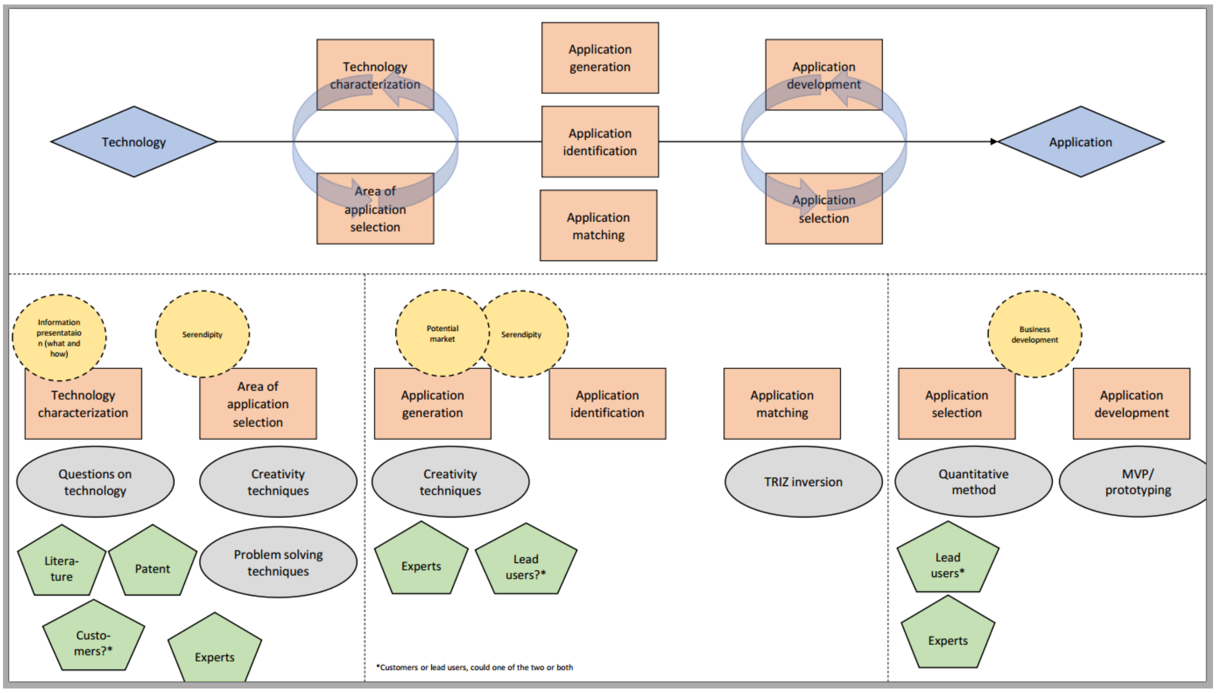
I do not think the method you developed is not the only method to find applications for technology or for organic molecules, but I do think it is a way that could work.

Good to realize that the framework I am creating is not a all-encompassing framework that people will always follow, but rather a tool that can be used at will. There will applications that will be found without any of the steps in the framework.

Something else you might want to consider is to present your work, preferably before your defence, to a product development unit at DSM. I will check whether they are interested.

Some last comments, I would change the "technology" at the start of your framework into "organic molecule". On top of that, you identify an area of application, rather than selecting it.

The framework that was sent to Gabrie is depicted below:



I.5 Interview dr. P. Lips (candidate 12)

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What do you think of the framework is it is presented now?

In general, I think it makes sense. However, I do feel like there needs to be an explanation with the framework to be able to follow along.
On top of that, I think the serendipity you present for the area of application identification should also be incorporated into the technology characterization. Based on my own experience, it is serendipity that plays a major role in identifying alternative application possibilities when doing research on a technology (with an already identified area of application).

How would you approach making the framework more specific towards organic molecules? Posed differently, how would you go about finding an application for a molecule that you have made in the lab?

Usually, anything you make in the lab you make with a specific purpose. If not that, you at least make it within a certain area of expertise. For example, I have worked a lot with semi crystalline polymers.
Now it is very important to get information about your molecule. For polymers, you would want to know the mechanical properties and the thermal properties.
However, these polymers are not really new from an organic chemistry standpoint. I combined some well-known raw materials/chemicals into monomers and created a polymer from that. For example, the properties of the polymer can be new because of a specific order of the monomers in the polymer chain leading to unique crystallization behaviour and thermal properties. This can also lead to specific physical and mechanical properties.

It is important for me to properly define what I mean with a "new organic molecule". I do however think what you describe falls in that category. The polymer or even the monomers were not trivial, they were new. The raw materials or the chemistry does not have to be new to yield a new molecule.

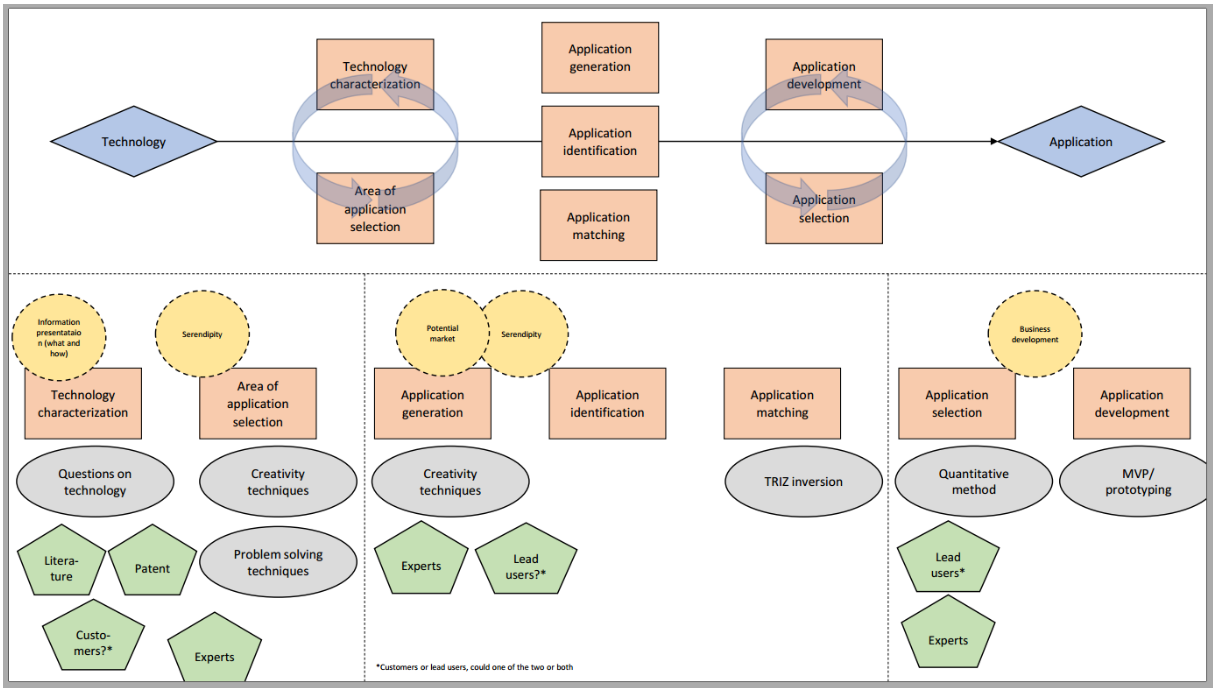
Fair enough, however I would think that polymer chemists do not see a new polymer as a new organic molecule.

Coming back to my question, you have a flask with an organic substance in there and you want to find an application for this substance. What do you do?

First I would isolate the substance, aka purify it and after that determine the structure (in between you do a solubility test, this is a big determinant in the type of spectrometry you can use in the determination of the structure).
From there you have to determine the properties you need to know. A basis could be to measure thermic and physical properties. You could add to these the electric and mechanical properties and even the somewhat exotic magnetic properties. However, I think the determination of what to measure is very much depended on your background and your surroundings. If you work in a polymer lab like I did and you are used to working with crystalline and biodegradable polymers, you very quickly jump to the conclusion that you should measure the thermic and mechanical properties. However, for someone working in the field of solar cell polymers, they would start with measuring the optical properties.

I think defining a overall standard set is very difficult, it depends on the type of lab you work on and on the expertise of your colleagues.

The framework that was sent to Priscilla is depicted below:



I.6 Interview dr. W.F. Jager (candidate 16)

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How would you approach a categorization of organic molecules, starting from scratch?

I would start by differentiating between materials and biologicals. Materials are polymers, molecules for energy applications, etc., while biologicals are the pharmaceuticals etc.
I think it is important to realize that going from a molecule to a material is a black box. You can characterize a molecule, but if you make a material from this molecule, it might behave different than what you would expect based on the molecule.
On top of that, sometimes you want the behaviour of a single molecule on macro scale, and not the behaviour of the collective substance. For example, perylenes, which have very good fluorescent properties in a dissolved state of in a single molecule state. However, a regular solid of these molecules does not have this property (a solution for this specific problem is embedding the perylene in an organic framework in which it can behave as a single molecule).

Let us from here take a step back and try to further specify the different categories of materials and different categories of biological.

Materials include coatings, surfactants, polymers and materials in energy and battery applications (some of these molecules can also be used in water purification applications, which is more on the side of biologicals).
Biologicals include toxins, pharmaceuticals and molecules for water purification applications.

What I recognize from this list is that it is very hard to categorize molecules in categories that all have the same level of detail. For example, “polymers” and “materials in battery applications” sounds to me like a different level of detail.

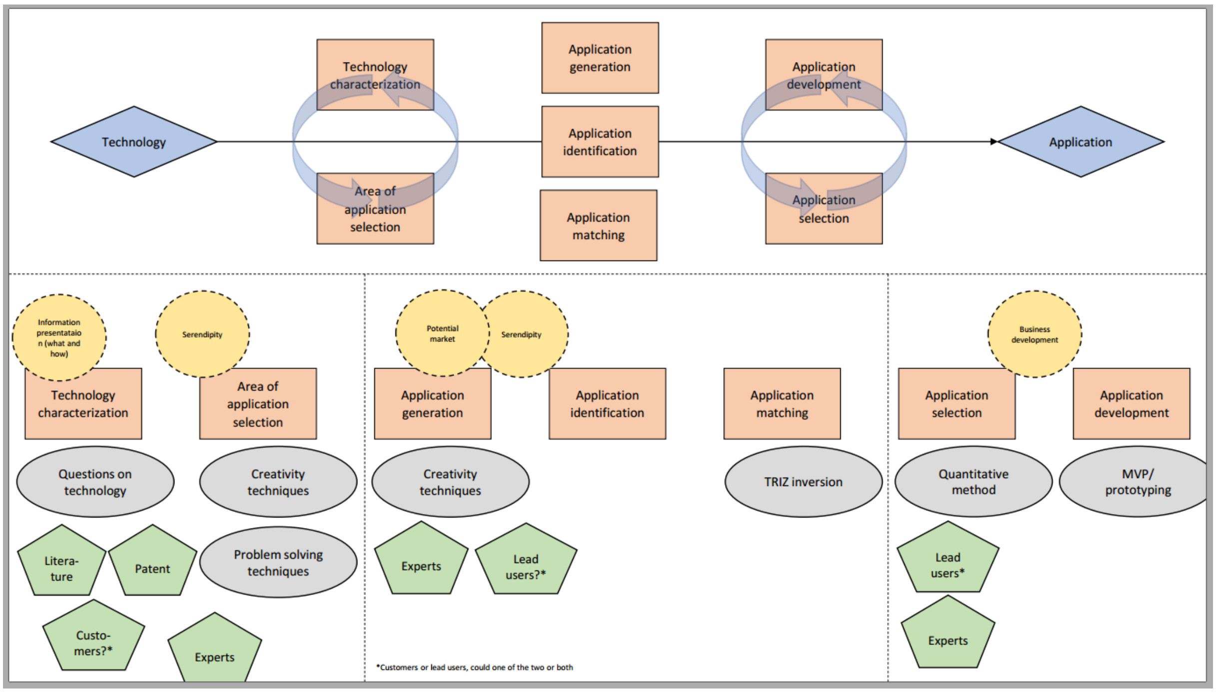
Do you think it would be possible to reason the other way around, finding different application fields for organic molecules and discovering which characteristics make a molecule a fit for a certain application?

Yes, I think that could work in theory.

If you had to find potential applications for some molecule for which you do not know anything, but you have the molecule available to you, how would you go about it?

I would start with a basic characterization, which is determining and proving the chemical structure. From there, you can start to think of potential fields of application and subsequently decide what you need to know about the molecule in that specific application field.

The framework that was sent to Wolter is depicted below:



Appendix J - TRIZ

Parameter number	Parameter title	Parameter number	Parameter title
1	Weight of a mobile object	**21**	Power
2	Weight of a stationary object	**22**	Loss of energy
3	Length of a mobile object	**23**	Loss of substance
4	Length of a stationary object	**24**	Loss of information
5	Area of a mobile object	**25**	Loss of time
6	Area of a stationary object	**26**	Amount of substance
7	Volume of a mobile object	**27**	Reliability
8	Volume of a stationary object	**28**	Accuracy of measurement
9	Speed	**29**	Accuracy of manufacturing
10	Force	**30**	Harmful factors acting on an object from outside
11	Tension / Pressure		
12	Shape	**31**	Harmful factor developed by an object
13	Stability of composition	**32**	Manufacturability
14	Strength	**33**	Convenience of use
15	Time of action of a moving object	**34**	Repairability
16	Time of action of a stationary object	**35**	Adaptability
17	Temperature	**36**	Complexity of a device
18	Brightness	**37**	Complexity of control
19	Energy spent by a moving object	**38**	Level of automation
20	Energy spent by a stationary object	**39**	Capacity / Productivity

Table 17: The 39 engineering parameters of TRIZ, adapted from [99].

Principle number	Principle title	Principle number	Principle title
1	Segmentation (Fragmentation)	**21**	Rushing through (Skipping)
2	Extraction (Taking out)	**22**	Convert harm in to benefit
3	Local quality	**23**	Feedback
4	Asymmetry (Symmetry change)	**24**	Mediator (Intermediary)
5	Consolidation (Combining)	**25**	Self service
6	Universality (Multi functionality)	**26**	Copying
7	Nesting (Matrioshka)	**27**	Dispose
8	Counterweight (Anti-weight)	**28**	Replacement of a mechanical system
9	Prior counteraction	**29**	Pneumatic or hydraulic construction
10	Prior action (Do it in advance)	**30**	Flexible films or thin membranes
11	Cushion in advance (Cushioning)	**31**	Porous materials
12	Equipotentiality	**32**	Changing the colour
13	Do it in reverse (The other way around)	**33**	Homogeneity (Uniformity)
14	Spheroidality (Curvature)	**34**	Rejecting and regenerating parts
15	Dynamicity (Dynamics)	**35**	Transformation of properties
16	Partial or excessive action	**36**	Phase transition
17	Transition into a new dimension	**37**	Thermal expansion (Relative change)
18	Vibration	**38**	Accelerated oxidation
19	Periodic action	**39**	Inert environment
20	Continuity of useful actions	**40**	Composite materials

Table 18: The 40 inventive principles of TRIZ, adapted from [99].

Parameter number	Parameter title	Parameter number	Parameter title
1	Weight of a mobile object	**21**	Power
2	Weight of a stationary object	**22**	Loss of energy
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4	Length of a stationary object	**24**	Loss of information
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Table 19: The 39 engineering parameters of TRIZ, adapted from [99].

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Table 20: The 40 inventive principles of TRIZ, adapted from [99].

Appendix K – Basic design cycle

In this appendix, I would like to briefly introduce the basic design cycle. A graphical representation of the basic design cycle can be found in figure 34. As can be seen from the figure, the basic design cycle is a cyclic design process that might be repeated a number of times. The five of the six actions (black text in figure 34) are described in the Delft design guide [16]:

- In the analysis, the aspects related to the design goal or design problem are assessed. The outcome is a list of design criteria.
- In the synthesis, potential solutions are created. Ideation is an important part of this process.
- In the simulation, the ideas from the previous phase are drawn and modelled.
- In the evaluation, the design criteria are used to assess the current design.
- Lastly, the decision moment is used to assess if the current design is acceptable or not.

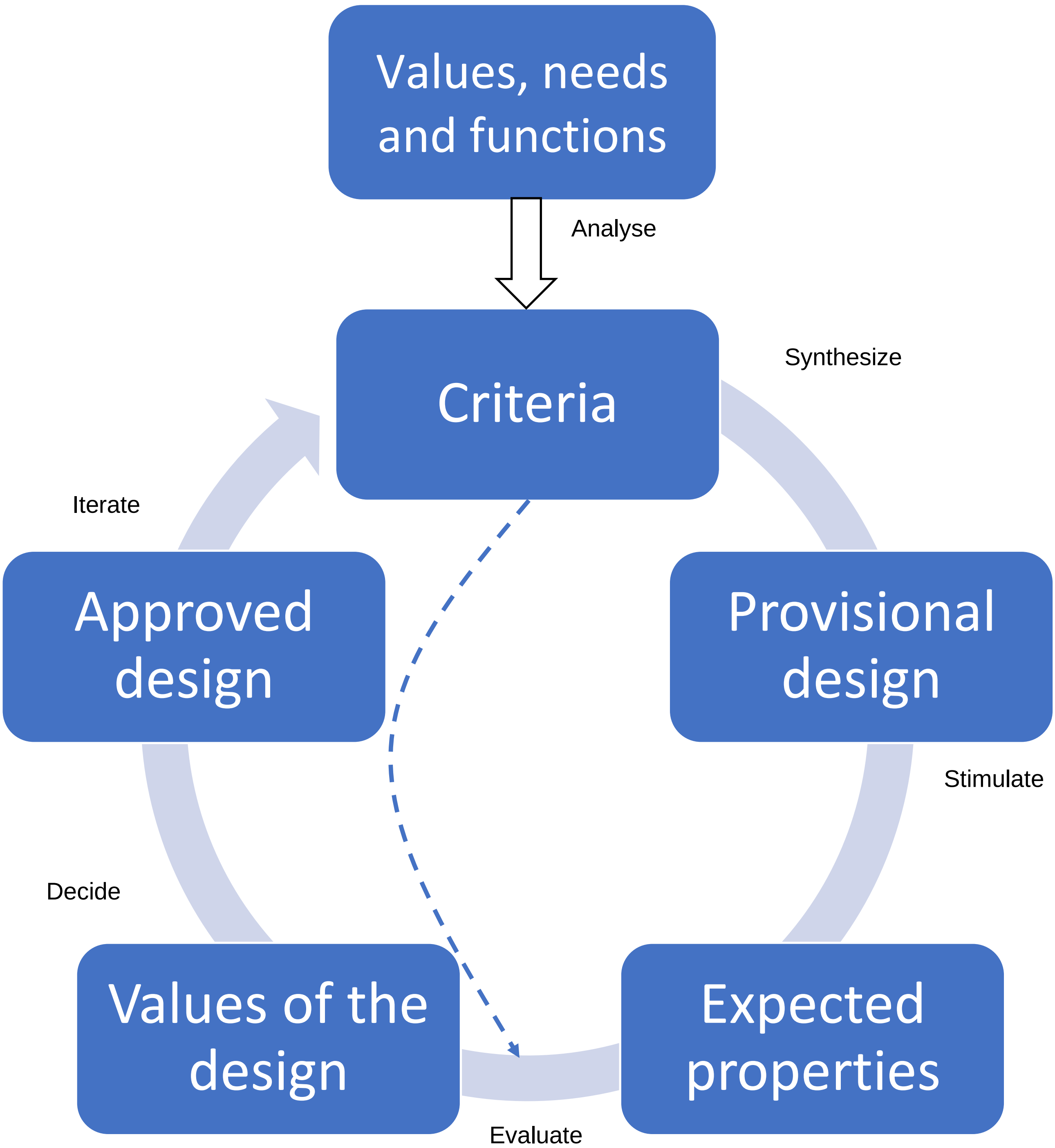

Figure 34: The basic design cycle, adapted from Boeijen et al. [16].