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A Framework for Concept and its Testing on Patents

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Abstract. The development of a concept for a system is a key step towards creating the system's architecture. Most previous concept development approaches focus on the procedures for the conceptual design activity - the sequence of activities and tasks. Our work is motivated by the desire to move the activities executed in a Concurrent Design Facility more upstream, in order to include choices and trade-offs among potential system concepts in a digital environment. Therefore, the objective of this work is to develop a *concept framework* that can systematically represent the concept's constituents, their definitions and interconnections, such that it can be used in a computational environment. We propose a concept framework that is based on six assertions rooted in design theory, that lead to 33 entries in the framework. In order to test the completeness and utility of this framework, we have mapped eight selected US patents to the framework. Patents are a legally viable means for defending an invention, and therefore the patents must logically contain a description of the concept underlying the invention. For this small N study, we chose eight US patents that represent a broad spectrum of engineering systems and methods. The success of this mapping from patents to the proposed concept framework is a necessary condition to demonstrating the completeness and utility of the framework.

Introduction

Conceptual design is one of the most challenging and crucial stages of the product development process. The importance of this phase has been widely highlighted in literature. For example, Kroll et al. mentioned that the conceptual design "significantly affects the product novelty, performance, robustness, development time, value, and cost" (Kroll et al. 2001). Suh comments: "In the conceptual design stage, design decisions have the greatest impact on the project outcomes with respect to functionality, performance, appearance, costs and sustainability" (Farid and Suh 2016). In our work we demonstrate a concept framework that represents the concept's constituents, their definitions and interconnections.

The objective of this work is to develop and present such a concept framework. This framework comprises the important information containing the key constituents of concept, and can be represented digitally. In this paper we map eight patents, representing a broad spectrum of engineering systems and methods, to the concept framework. Patents have been chosen as the unit of knowledge, as these are internationally recognized ways to protect an invention. Therefore, the patents must logically contain a definition of the underlying concept included within the invention. Success in demonstrating that the patents can be mapped to the concept framework is therefore a necessary condition to demonstrating the completeness and utility of the concept framework.

Such a concept framework might have several forms of utility. Our original motivation was to enable conceptual design in a concurrent engineering design environment. The proposed concept framework contains a formal body of descriptive data that serves this purpose, enabling the analysis of existing systems and synthesis of new ones in a model-based environment. In addition, the models of concept that are built on the basis of proposed methodology can help to fully populate the space of possible concepts, and reveal the alternative and previously unexplored concepts in a concise and effective way.

Another important utility of the concept framework is that it leads seamlessly to architecture development. The approach leads to the definition of a concept by a subset of the specific information that will eventually be used to describe the architecture. Thus concept knowledge is not lost but is reused in architecture.

Background

Concept is not a precisely defined idea. According to Crawley et al., concept is "a product or system vision, idea, notion, or mental image that maps function to form. It is a scheme for the system and how it works. It embodies a sense of how the system will function and an abstraction of the system form. It is a simplification of the system architecture that allows for high-level reasoning" (Crawley et al. 2015). Another definition, proposed by Ulrich and Eppinger, states that a concept is "an approximate description of the technology, working principles, and form of the product. It is a concise description of how the product will satisfy the customer needs" (Ulrich and Eppinger 2011). These two definitions have a number of features in common. We can conclude that the *concept* has a form, function, and initial hints about how the system works – the concept of operations. The form is the physical embodiment of the system, while the function outlines what processes the system is performing. These definitions are a key starting point for this research, as they create an appropriate level of abstraction for the concept framework. The definition of concept and related models by other authors will be discussed below (Andreasen, Wallace, Cash 2015; Hubka 1973; Andreasen 1992; Ferreirinha 1990; Jensen 1999; Mortensen 1999; Hatchuel and Weil 2003).

According to INCOSE, the purposes of the concept stage is to identify stakeholders' needs, explore concepts, and propose viable solutions (INCOSE Systems Engineering Handbook 2006). The focus of the handbook is on what should be done during this life cycle stage, as opposed to the methods and tools to be used. This creates a research opportunity to explore the notion of concept itself.

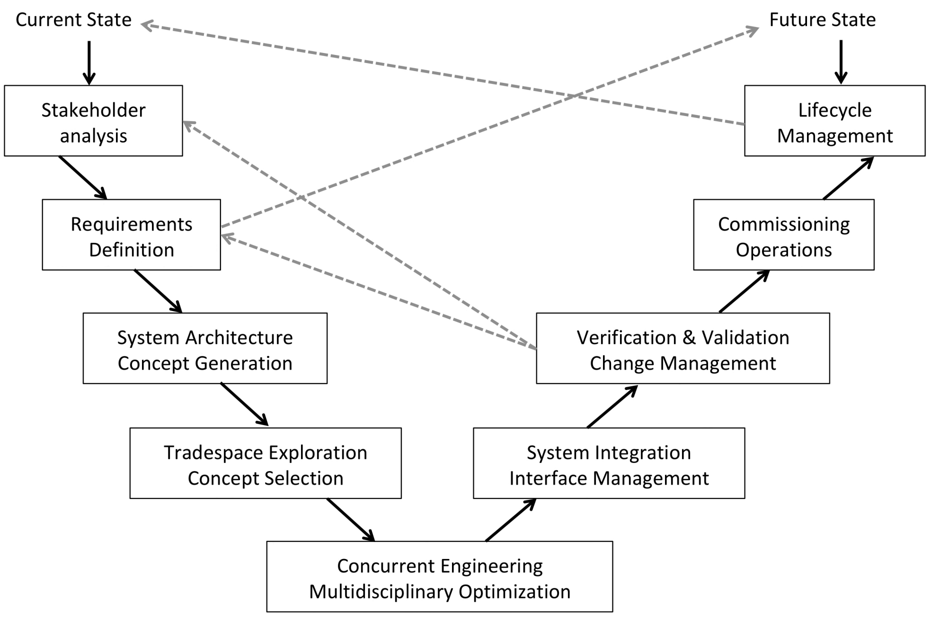

Figure 1. V-model (from de Weck 2015)

In our work we are concentrating on the exploration of the concept's essence and constituents, aimed at specifying the exact amount and nature of information required to define the concept. Our work corresponds to the INCOSE’s specification of the concept stages. As it will be shown later, the concept framework is built upon six assertions, the first of which references INCOSE’s process of stakeholder consideration. INCOSE’s phase of concept exploration is covered by the remaining five assertions dedicated to solution-neutral information, and to solution-specific information, all formulated at the level of an integrated concept. With reference to the V-model presented in Figure 1, the concept framework should cover stakeholder analysis, requirement definition and concept generation, but stop short of elaboration of the architecture.

The Concept Synthesis Model (Figure 2), is an integral part of the Encapsulation Design Model (Andreasen, Wallace, Cash 2015). According to authors, the concept synthesis consists of three major steps: goal formulation, ideation, and evaluation and choice. Although the output from these steps is a concept that is further used in the product synthesis, the nature of the description is still procedural.

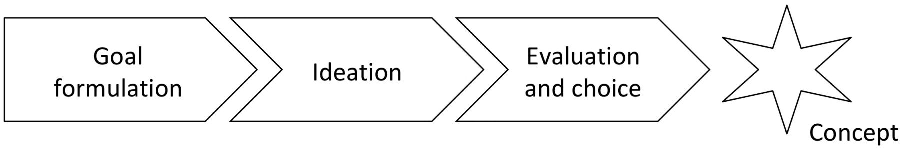

Figure 2. Three major steps of Concept Synthesis Model (from Andreasen et al. 2015)

Hubka formulated the Theory of Technical Systems (Hubka 1973), which has been transformed by Andreasen into the Domain Theory (Andreasen 1992). This theory attracts our attention, as Andreasen proposed strict domains that are required for the design process. Each of these domains has its own “language”, allowing the designer to “spell a product in different ways”. Packing this theory into the Chromosome model (Ferreirinha 1990) reveals the interconnectivity between entities of different domains, as it is shown in Figure 3. Note that the model has gradually been changed (Jensen 1999; Mortensen 1999).

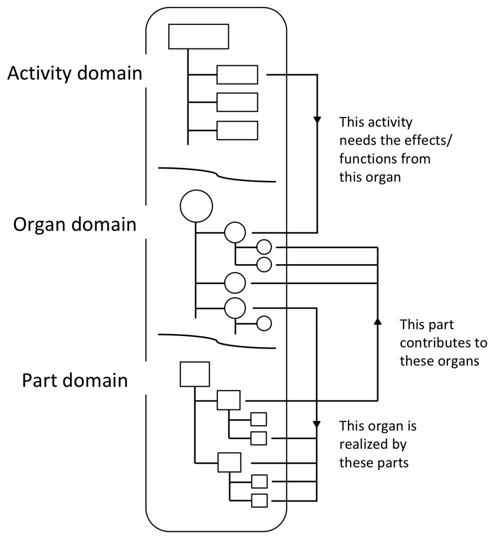

Figure 3. Three domains of domain theory

There is some common ground between Andreasen’s theory and our framework. Our concept framework represents the entities that perform the functions – the operands and processes – as well as the elements of form. By assigning the entities of process to elements of form, we allow designers to capture the concept in a strict notation. A main difference with Andreasen’s approach is in the level of detail that is present in the model. The concept framework has formal and functional relationships, as well as structure, context and the concept of operations.

C-K theory is an approach aiming at explanation of concept emergence (Hatchuel and Weil 2003). In this theory Hatchuel and Weil distinguish concept (Concept Space) and the knowledge (Knowledge Space). According to them, the concept is a proposition that has no logical status in the knowledge space. Thus, the authors define a design as "the process by which a concept generates other concepts or is transformed into knowledge, i.e. propositions in the knowledge space." (See Figure 4).

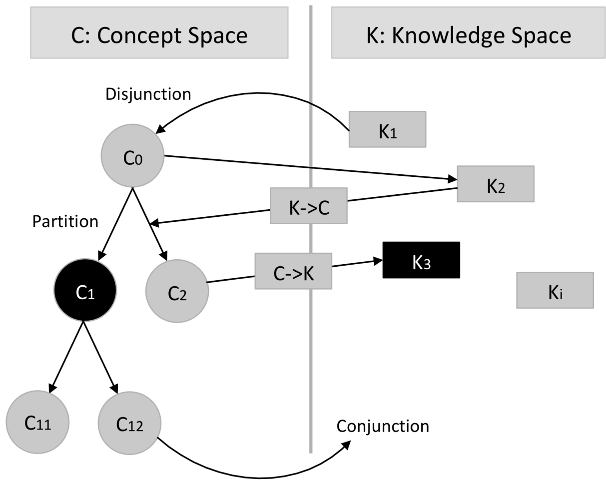

Figure 4. C-K dynamics (from Hatchuel and Weil, 2003)

The important notion that C-K theory provides to the designer is the inheritance of the previous knowledge in the newly generated knowledge emerged by means of concept. This logical construct has some common features with our concept framework, as the movement from solution-neutral to solution-specific becomes possible when the previous knowledge, or generalized function in solution-neutral environment, is mapped to the new knowledge, or specialized function in solution-specific environment.

It is desirable that a concept framework be represented by one of several common modeling languages. For instance, the system modeling language (SysML) has a grammar of nine types of diagrams that support the specification, analysis, design, verification, and validation of systems. The Object-Process Methodology (OPM) is an example of a modeling approach that is able to represent the system graphically in a significantly smaller number of diagrams than SysML (Dori 2002). Another advantage of OPM is that it has both linguistic and graphical representations, one of which can be generated from the other in OPCAT (Dori et al. 2003). OPM is now specified in ISO 19450 (ISO 2015). We will adopt OPM as the modeling language for the concept framework.

Goal and overview

The specific goal of this paper is to define the *core idea* of concept as form and function in the solution-specific environment (the solution statement). This *core idea* is surrounded upstream by information about the stakeholders and their needs, which then flow, still upstream, to the solution-neutral problem formulation (a functional requirement). Conceptual design is then the specialization of the solution-neutral to solution-specific domains. In addition to the stakeholder needs, solution-neutral problem formulation and solution-specific solution statements, the concept framework may also contain more detailed information about internal form and function, called the integrated concept, as well as contextual elements and concept of operation. It is a goal of this research to define the extent of information necessary to specify into a concept framework.

Another goal of the paper is to validate the framework by mapping eight patents broadly representative of engineering systems and methods to the concept framework. The ability to map patents to the concept framework is a necessary condition to show its completeness and utility for a broad spectrum of engineering systems. If successful, such a concept framework could be used for two purposes: the analysis of existing systems such as disclosed in the patents; and the development of new systems. The primary value of the concept framework is that it rigorously outlines the concept of the system that subsequently leads to the architecture of the system (Crawley et al. 2015).

In the following section we present the six assertions of the concept framework, as well as introduce the concept framework, rigorously defining concept and integrated concept and their constituents. We present the idea of the solution-neutral and solution-specific environments and demonstrate how the concept framework spans both environments. After a brief discussion of the utility and structure of patents, we show the methodology for mapping patents to the concept framework. After this we demonstrate, through a small N study, that there is a common scheme for how information is presented in patterns, and that the framework can capture all of the important information in a patent.

Concept framework

Concept framework is built upon six assertions that are demonstrated in Figure 5. They will subsequently lead to the 33 entries of concept framework.

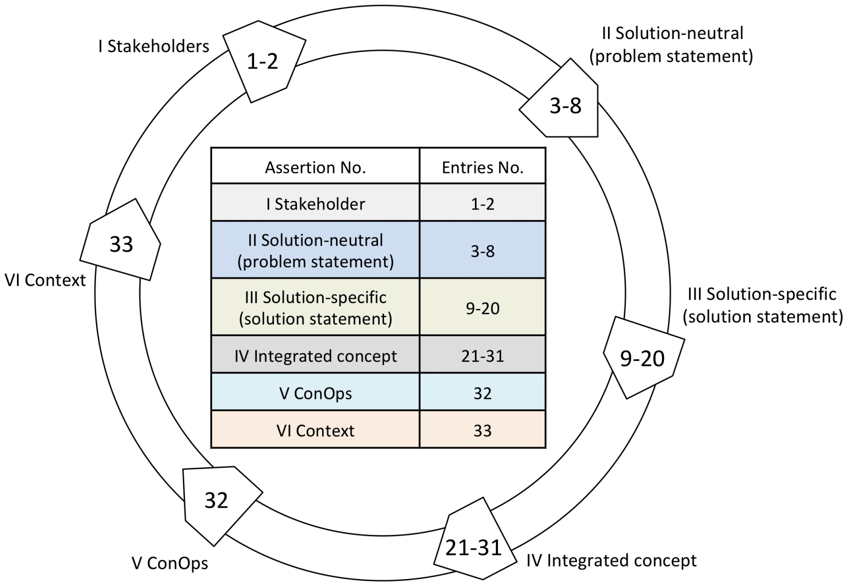

Figure 5. Six assertions of the concept framework

In this section we will also introduce the canonical representation of a system, and will use it to represent conceptual design and the concept framework. The concept framework contains essential information potentially necessary to define the concept of a system.

Representation of conceptual design

Any system can be described by means of three main entities: the *form* (the instrument object), a *process* (a transformation), and an *operand* (an object that is changed by the process). Together the process and operand are called the *function* of the system. The canonical representation of a system is shown in Figure 6a using objects and processes, as the name Object-Process Methodology implies (Soderborg et al. 2003). Note that the relationship between the operand and process is shown by a closed-headed arrow, while the instrumental relationship between the form and the process is represented by a circular-headed "arrow."

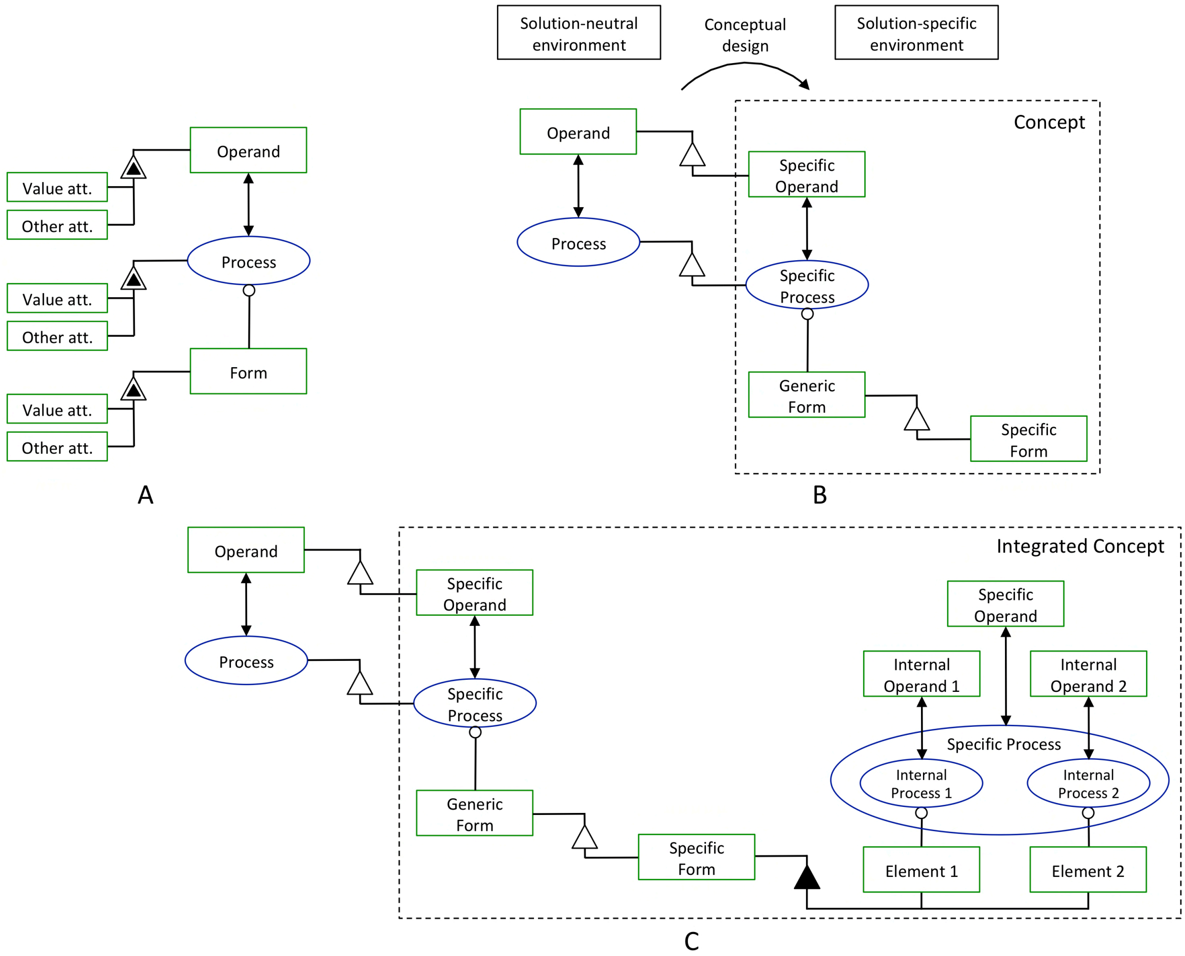

Figure 6(a). Canonical representation of system showing objects, processes, links and attributes; 6(b). Representations of conceptual design; 6(c). Conceptual design extended to include the integrated concept.

Each entity might have value-related *attributes* or other attributes, which describe the object or process, and are indicated by the partially filled triangle. Generally, value is created when the value-related of the operand is changed, and when the value-related attributes of the process and the form are satisfied. We will use this canonical model to explore concept.

Figure 6b represents the rigorous definition of the *concept* of a system (Crawley et al. 2015). The concept contains a specific operand, specific process and specific form. It exists in the solution-specific domain and conveys the solution. (Note that on Figures 6b and 6c the attributes have been suppressed for clarity). In the solution-neutral domain on the left of Figure 6b, we also express the solution-neutral problem function by means of an operand and process.

Conceptual design then involves a specialization from the solution-neutral environment to the solution-specific environment. In this sequence, the operand is specialized to the specific operand (specialization is represented in OPM by the unfilled triangle), the process is specialized to the specific process, and the specific form is defined.

Figure 6c shows an extension of concept by one level of decomposition to reveal an *integrated concept*, which inherits all the features of the concept for the system. This provides for the possibility that essential information about the concept might be hidden one level of decomposition lower than the concept itself. The form is decomposed into elements – decomposition is indicated by the filled triangle. These elements work as instruments of internal processes potentially acting on the internal operands. Reading Figure 6c in reverse demonstrates *emergence* – the internal processes act on the internal operands in such a way as the specific process emerges working on the specific operand.

An example of conceptual design

In order to demonstrate the process of conceptual design, we will use the example of an air transportation service. The first step in using the concept framework is actually upstream of Figure 6c - the identification of stakeholders and their needs. Let us assume the stakeholders are members of the public, and their need is to visit family in a distant location. Once the stakeholders and their needs are defined, these needs should be translated into functional goals in the solution-neutral environment. This environment contains the solution-neutral process and solution-neutral operand, but does not contain the instrument of execution.

Applying the template of Figure 6b, we would obtain "traveler" as the solution-neutral operand and "changing location" as the solution-neutral function. Complete with attributes, the solution-neutral function is "safely and on demand changing the location of a traveler of mass 70 kg" as shown in Figure 7.

Our next step is to fill in the integrated concept of Figure 6c. In this case, the specific operand is the same as the solution-neutral one – the traveler. Sometimes this happens – the solution-specific operand is the same as the solution-neutral one, and sometimes the specialization reveals a new operand. Here we see one of the utilities of the proposed concept framework: the ability to capture the alternative solutions and to represent them analytically in a model-based manner. For instance, there are many options about how the function "changing location" can be specialized in this case. In order to change the location, processes such as "flying," "rolling," or "floating" can be used. We chose the "flying" process as indicated in Figure 7. Next the generic and specific forms are specified respectively as "a flying device" and a "jet aircraft." Other options might include rockets, helicopters and blimps.

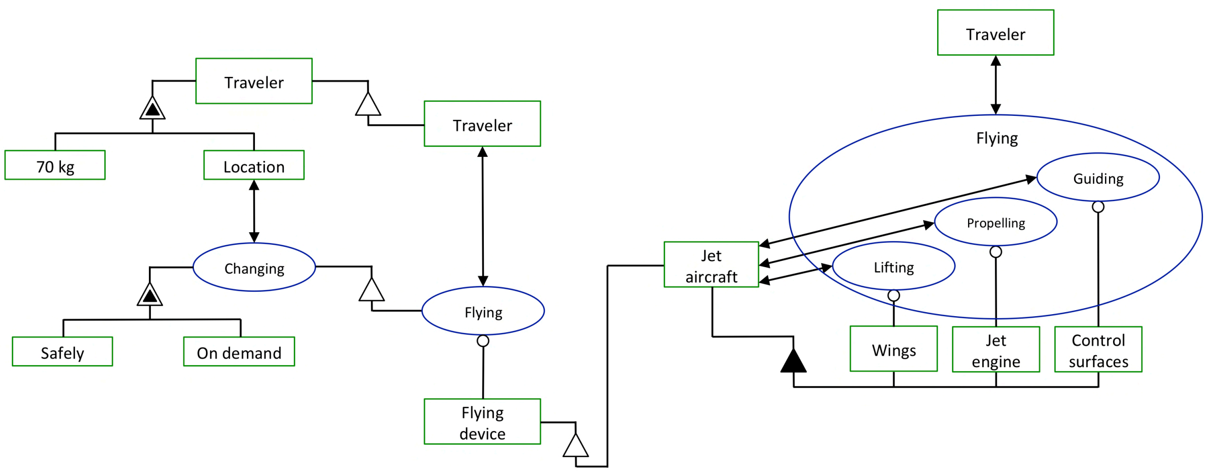

Figure 7. Integrated concept framework for air transportation service

By specializing "traveler" as the operand, specializing the process from "changing" to "flying", we are executing conceptual design. In other words, we are crossing that imaginary barrier between the solution-neutral and solution-specific environments. The outcome of such specialization is that once we know the solution-specific function, we are able to assign the generic form to it.

"Flying" is a rich concept, and in order to explain this concept, it might be necessary to reveal three internal processes: lifting, propelling, and guiding. The instruments of these processes are wings, jet engine, and control surfaces, correspondingly. Note that in this particular case the specific form is the jet aircraft itself. But the emergent function is still "flying the traveler."

This example illustrates conceptual design as the specialization from the solution-neutral and to the solution-specific environments, and the extension of concept by one level to reveal something about internal working of the system.

The complete concept framework

It is our hypothesis that the complete concept framework needed to specify a concept includes all of the information on Figure 6c: the solution-neutral problem statement of function, plus the solution-specific integrated concept. In addition, it implicitly contains the attributes of all of these entities.

We propose that the other entries needed to specify a concept include: the stakeholders and their needs (upstream); and some aspects of the concept of operations, structure and interactions, and context. Figure 8 shows the questions that when answered will yield the 33 entries of the framework. We hypothesize that when these 33 entries are known, this framework will contain all of the information necessary for capturing a concept.

Stakeholders	Solution-neutral (Problem statement)	Solution-specific (Solution statement)	Integrated concept	Concept of Operations	Context

1. Who are the **stakeholders**?	9. What is the **solution-specific operand**?	21. What is the **internal operand**?
2. What are the **needs of stakeholders**?	10. What is the **value attribute** of the solution-specific operand?	22. What is the **value attribute** of internal operand?
3. What is the **solution-neutral operand**?	11. What is the **other attribute** of the solution-specific operand?	23. What is the **other attribute** of internal operand?
4. What is the **value attribute** of the solution-neutral operand?	12. What is the **solution-specific process**?	24. What is the **internal process**?
5. What is the **other attribute** of the solution-neutral operand?	13. What is the **value attribute** of the solution-specific process?	25. What is the **value attribute** of internal process?
6. What is the **solution-neutral process**?	14. What is the **other attribute** of the solution-specific process?	26. What is the **other attribute** of internal process?
7. What is the **value attribute** of the solution-neutral process?	15. What is the **generic form**?	27. What is the **element** of specific form?
8. What is the **other attribute** of the solution-neutral process?	16. What is the **value attribute** of the generic form?	28. What is the **value attribute** of the element of specific form?
	17. What is the **other attribute** of the generic form?	29. What is the **other attribute** of the element of specific form?
	18. What is the **specific form**?	30. What is the **structure**?
	19. What is the **value attribute** of the specific form?	31. What are the **interactions**?
	20. What is the **other attribute** of the specific form?	32. What is the **concept of operations**?
		33. What is the **context**?

Figure 8. The questions for the 33 entries in the concept framework

Patents

Patents are one of the most common ways to protect the rights of an inventor. According to the United States Patent and Trademark Office (USPTO), a *patent* is "a property right granted by the Government of the United States of America to an inventor 'to exclude others from making, using, offering for sale, or selling the invention throughout the United States or importing the invention into the United States' for a limited time, in exchange for public disclosure of the invention when the patent is granted" (USPTO 2007). Note that the patent doesn't provide a right to make, use, offer for sale, sell or import, but provides the right to exclude others from making, using, offering for sale, selling or importing the invention.

Patents also have utility to other users. In accordance with the World Intellectual Property Organization (WIPO), "it is estimated that some 70% of the information disclosed in patent documents have never been published anywhere else." (WIPO 2016)

From the perspective of this study, patents represent a large database of publically accessible documents, describing new inventions in some detail. The patents must logically describe the concept underlying or contained within the invention. Success in demonstrating that the patent can be mapped to the concept framework is therefore a necessary condition to demonstrating the completeness and utility of the concept framework.

Structure and content of patents

US patents are structured according to internationally agreed standards. The information in a patent is presented as a combination of structured and unstructured data. The structured data includes the template of a patent while the unstructured data includes the text.

From the formal point of view, we may highlight that the patents consist of three main parts: the abstract in the front page, the description of the invention, and the claims. The roles of these parts are:

- The abstract at the first page of the patent briefly explains the core of the invention and the elements of form;
- The description of the invention outlines the technical field of the invention. It also contains a detailed description of the invention, including its form and function; it also provides information about the concept of operations of the system;
- The claims describe the scope of the invention and the technical features of it. The claims identify the features of the invention that are distinct from all previous inventions. The claims section is the part of the patent that has a legal importance.

Patents can be issued for systems (machines), methods (processes, acts), and the composition of matter (chemical compounds, chemical compositions).

Methodology of mapping patents to the concept framework

Sampling of patents

This section describes the methodology of the mapping patents to the concept framework. The first step is to construct the set of sampled patents. In order to be methodologically correct, we were guided by sampling techniques for "small N" qualitative studies (Trost 1986). We listed the "independent" variables appropriate for the purposes of our study. These "independent" variables focused on the types of systems and methods that are represented in patents. In order to test for broad applicability, we chose four quite different types: biological, thermodynamic, electro-mechanical, and software. In addition, we wanted the set to include methods patents, systems patents, and some that were both method and system patents.

This yielded eight patents in the four types:

1. Vehicle mounted traffic light and system (US Patent 9318021);
2. Traffic signal device for driver/pedestrian/cyclist advisory message screen at signalized intersections (US Patent 9153128);
3. System and method for launching a browser in a safe mode (US Patent 9292701);
4. System and methods for detection of fraudulent online transactions (US Patent 9363286);
5. Method to generate novel bioactive molecules (US Patent 9080199);
6. Methods and compositions for enhanced delivery of bioactive molecules (US Patent 6706289);
7. Heat exchanger arrangement for turbine engine (US Patent 9212623);
8. Heat engine and heat to electricity systems and methods (US Patent 8096128).

Mapping the patents to the concept framework

In order to introduce a rigorous process for mapping patents to the concept framework, we assigned a number to each one of the 33 entries of the framework that is presented in Figure 8. Entries 1 and 2 are related to stakeholders and their needs; 3-8 deal with the solution-neutral environment; 9-20 are related to the solution-specific environment or concept; entries 21-29 are concerned with integrated concept; and 30-33 deal with structure, interactions, concept of operations and context, respectively. Note that if only the information suggested in Figure 6b (the solution-neutral problem and core solution-specific concept) were represented, entries would only be found in the patent under entries 3-20.

The text of each of the eight patents was analyzed, and the outcome summarized as the answers to two questions. The first question simply asks if this specific entry is used to map the patent to the framework. The second question asks for each of the 33 entries: where in the patent the information about the entry is located. This allows us to see how the information on the 33 entries is spread throughout the patent.

Outcomes of experiment

Need for an extended conceptual design representation

The results of the mapping for the small N sample of patents is shown in Figure 9, which summarizes the outcomes for the two questions: is the entry used to map the patent (this information is also shown in Figure 10), and where in the patent is the information drawn from? The left column contains the 33 entries (the bolded entries are objects, processes and relationships, and the remainder are attributes). The column labeled “occurrence” shows the percentage of the eight patents that used the entry in mapping the patent. The remaining eight columns indicate where in the patent (Abstract, Description and Claims) the entries appeared.

The first important conclusion is that, broadly speaking, the complete concept framework is needed for mapping a patent, and not just the information at the core of the concept (entries 3-20). In particular, the stakeholder information (1-2) is vital, as is the integrated concept (21-29), and the relationship information (structure, interactions, concept of operations and context 30-33). Using the more restrictive definition of concept in Figure 6b would not be sufficient, as it is only partly describes the concept. As it can be seen in figures 9 and 10, such entries of concept framework as solution-neutral operand and process (entries 3 and 6), solution-specific operand and process (entries 9 and 12), generic form (entry 15), and specific form (entry 18) are always present in patents.

An especially strong result is that the claims, the intrinsic parts of any patent, are primarily reflected in the first level decomposition of the integrated concept (21-29). Every patent maps claims to the internal operands, processes and elements. There is clearly an underlying force at work here. For a patent to describe the invention in a legally defensible way, the patent must decompose the invention into a number of pieces and explain what each one of the pieces does. Each one of such pieces composed of internal element that is used to execute the internal function (internal process plus internal operand). It is also an opportunity to engage the model-based conceptual design to represent the integrated concept.

Another observation is that the “other attributes” are almost never used in the mapping (entries 5, 8, 11, 14, 17, 20, 23, 26). Entry 29 “other attribute of internal element” was used only once, and the “value attribute” of the generic form was also not used (16). There is some sense to this. Since the person applying for a patent wants the coverage to be as broad as possible, it is in their interest to not restrict or constrain it by qualifications implied by these entries. It is likely that for patent analysis these ten entries could be omitted without loss of important information.

Name	# of Patent								Occu-rance, %
	1	2	3	4	5	6	7	8	
1. Stakeholders	D	D	D	D	D	A	D	D	100
2. Needs of stakeholders	D	D	D	D	D	D	D	D	100
3. Solution-neutral operand (SNO)	D	D	D	A	D	D	D	D	100
4. Value attribute of SNO	D	D	D	A	-	-	-	-	50
5. Other attribute of SNO	-	-	-	-	-	-	-	-	0
6. Solution-neutral process (SNP)	D	D	D	D	D	D	D	D	100
7. Value attribute of SNP	D	-	-	-	-	-	-	-	12,5
8. Other attribute of SNP	-	-	-	-	-	-	-	-	0
9. Solution-specific operand (SSO)	A, D	A, D	A	D	D	D	D	D	100
10. Value attribute of SSO	A, D	A, D	-	D	A	A, D	C	D	87,5
11. Other attribute of SSO	-	-	-	-	-	-	-	-	0
12. Solution-specific process (SSP)	A, D	A, D	A	D	A	A, D	C	D	100
13. Value attribute of SSP	A, D	A, D	A	-	-	-	-	-	37,5
14. Other attribute of SSP	-	-	-	-	-	-	-	-	0
15. Generic Form (GF)	D	D	D	D	D	D	D	D	100
16. Value attribute of GF	-	-	-	-	-	-	-	-	0
17. Other attribute of GF	-	-	-	-	-	-	-	-	0
18. Specific Form (SF)	A, D	A, D	A	D	A	A, D	A, D, C	A	100
19. Value attribute of SF	D	A, D	-	-	-	-	-	-	25
20. Other attribute of SF	-	-	-	-	-	-	-	-	0
21. Internal operand (IO)	D, C	D, C	D, C	C	D, C	C	A, D, C	C	100
22. Value attribute of IO	D, C	D, C	D, C	-	D, C	-	-	-	50
23. Other attribute of IO	-	-	-	-	-	-	-	-	0
24. Internal process (IP)	D, C	D, C	D, C	C	D, C	C	A, D, C	A, D, C	100
25. Value attribute of IP	-	-	-	C	-	C	A, D, C	A, D, C	50
26. Other attribute of IP	-	-	-	-	-	-	-	-	0
27. Internal element of form (IEoF)	D, C	D, C	D, C	C	D, C	C	A, D, C	A, D, C	100
28. Value attribute of IEoF	D, C	D	-	-	-	-	-	-	25
29. Other attribute of IEoF	-	D	-	-	-	-	-	-	12,5
30. Structure	D	D	D	D	D	D	A, D	D	100
31. Interactions	D	D	D	D	D	D	A, D	D	100
32. Concept of Operations	A, D	A, D	A, C	A, D, C	-	-	-	-	50
33. Context	D	D	D	D	D, C	D	D	D	100

Figure 9. The 33 entries in framework, its occurrence in the patents, and the part of the patent that maps to the entry (A, D and C indicate the information was found in abstract, description and claims respectively)

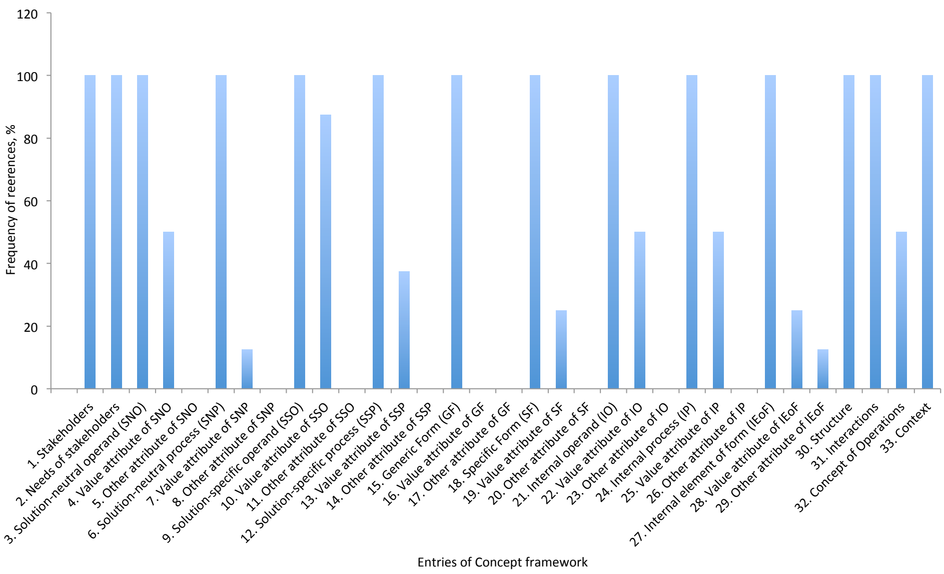

Figure 10. Occurrence of concept framework's entries in patents

Support for the concept framework

The small N examination of the patents revealed another important outcome – that the patent can be successfully mapped to the framework. The entries in the framework largely describe the concept represented in the patent. Such entities of the framework as the stakeholders and their needs, solution-neutral operand and process, solution-specific operand and process, generic form, specific form, the operands, processes and form of element, structure, interactions, concept of operation and context seemingly are capable of representing the content of a patent.

Recall that in the introduction we identified this as a necessary condition for the utility of the framework. We have demonstrated that the conceptual content of a patent can be mapped to the concept framework. Additional utility has been demonstrated. We can more clearly see the areas of emphasis in a patent, and in particular the role of the claims in describing the first level decomposition of the patent.

The concept framework comprises 33 entries. The framework can be used for two purposes: the analysis of existing systems and methods, such as disclosed in the patents; and potentially for the synthesis purposes aiming at the development of new systems. The concept framework can be represented in a model-based manner.

Especially important utility of the concept framework development is that it leads to the alternative concepts and finally to the architecture of the system itself.

Conclusion and future work

The aim of this work is to develop and demonstrate a concept framework that represents the concept's constituents, their definitions and interconnections. To achieve this goal, eight patents representing a broad spectrum of engineering systems and methods were mapped to the concept framework. This confirmed that the content of the patent could be mapped to the concept framework. This success is a necessary condition to showing the completeness and utility of the concept framework.

This framework contains all of the inheritable traits of a concept. If existing and new concepts were mapped to this framework, it would store the key information for subsequent use or alteration. A catalog of these entries would be a valuable part of conceptual design. Having available the concept framework representation of a wide set of concepts, the conceptual designer could more quickly and comprehensively search through the concept space.

An important specific conclusion is that the claims section of a patent, the key area of legal protection, contain information on form and function at one level of decomposition below the concept itself, in what we call the integrated concept.

There are a few directions of how this work can be extended. One of the possibilities is to map the larger systems and systems of systems to the proposed concept framework. This is also related to the more non-tangible systems like socio-technical systems.

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