Systems Thinking for Early Validation of User Needs in the Front End of Innovation; a Case Study in an Offshore SoS

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***Abstract*—This paper focuses on applying Systems Thinking for early validation of user needs in the front end of innovation for extending an offshore SoS with renewable energy. A high degree of uncertainty and ambiguity characterizes this early phase. Early validation of user needs is assumed to be a key for successful value creation in the early phase development of new systems. The user needs can be difficult to understand and subject to change due to the ambiguous nature of the innovation process. Systems Thinking is a mindset that increases understanding of the system´s context and behavior; it helps identifying possible leverage points. This paper applies Systems Thinking methodology in a real case for an industrial project adding renewable energy to offshore installations. We developed in this research graphical presentations to communicate system openness and user needs for the operational phase of the system. The graphical presentations were tested out on stakeholders. We found the Systems Thinking methodology and the graphical presentations to be helpful tools for successful stakeholder communication with the purpose of early validation of user needs.**

Keywords— early validation, user needs, Systems Thinking, renewable energy, front end of innovation, early phase systems engineering

I. Introduction

A. The Front End of Innovation

This paper focuses on the application of Systems Thinking to perform validation of user needs in the front end of innovation. The front end of innovation is the very first phase of a new product development [1], or the early phase of systems engineering [2]. This early phase is recognized as relevant for the success of the innovation and presents a great opportunity for the overall innovation process [3], [4].

In the front end of innovation, the system boundaries are usually unclear, and the uncertainty is high. There are several different variables acting upon the system that might change the concept and the path forward. Salado and Nilchiani [5] performed a literature review within Systems Thinking and confirmed the suitability of Systems Thinking on socio-technical problems to find effective solutions. Kjørstad and Falk “unpublished” [6] investigated the potential for a Systems Thinking mindset for effective decision-making in the front end of innovation in the offshore sector. Due to the high degree of complexity represented by the harsh and inaccessible offshore environment and the human interaction with the systems, Kjørstad et al. found the Systems Thinking mindset and the Cynefin framework [7] to be probable solutions to increase the innovation ability in this sector.

B. Early Validation of User Needs

According to Design Thinking, understanding *user needs is just as important as the technology and business aspects* in order to develop innovative solutions [8]. Kelley and Kelley describe innovation as the perfect balance of business, technology and human, as shown in Fig. 1 [9] p. 19.

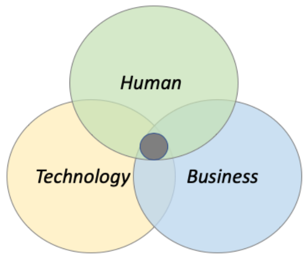

Fig. 1. The sweet spot of innovation [9]

Early phases of innovation tend to focus on business and enabling technology. The main concern is often to enable further funding of the project. The importance of validation of user needs, represented by the green “human” circle, is in risk of being neglected or found as not important in this phase.

There are several approaches for early validation of user needs. Kjørstad et al. [10] presented an overview of various early validation methods that have proven effective within their domains, such as stakeholder analyses and ConOps applied in traditional systems engineering, conceptual modelling applied in systems architecting, empathize with users through user research as advocated by Design Thinking, and the Business Model Canvas and Lean Canvas applied in business theory.

C. The Renewable Energy Addition of an Offshore SoS

This research is performed within a leading global company who provides subsea systems and installation services to the offshore oil and gas domain. Specifically, within a part of the company located in Norway that has provided subsea production systems to offshore oil and gas operators for the last 40 years.

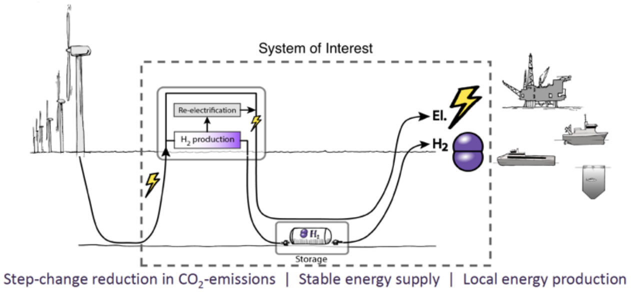

Fig. 2. The Deep Purple system and its context

The company has an increasing focus on developing sustainable solutions for their domain. They have initiated a front-end innovation project to develop a *renewable energy system for offshore consumers*. The project aims to supply stable CO_2-free energy to consumers. Fig. 2 shows the renewable system, named Deep Purple, and its context.

Deep Purple captures excess power from off grid wind farms and temporarily stores energy in the form of hydrogen subsea. The hydrogen can be transferred directly by pipeline to consumers offshore or onshore or converted to electricity for consumers nearby.

The company is in needs of a rapid approach to analyze the stakeholders of Deep Purple and their needs, and methods to cope with the complexity represented by the uncertainties and ambiguities in this early phase of the project. In this paper, we pursue *the applicability of the Systems Thinking methodology as a potential early validation method of user needs in the front end of innovation* for the offshore System of Systems (SoS).

Firstly, we present the research method. Then we present the current challenges and opportunities for the front-end innovation project. Further we apply the Systems Thinking methodology on the case and identify system boundaries, stakeholders and interests, graphical presentations and possible leverage points. Finally, we evaluate the results, and present our conclusions and future research.

II. Research Method

The basis for this research is industry-as-laboratory, a strategy often applied in research on systems engineering [11]. We have applied qualitative research methods using observations and informal interviews within a longitudinal time horizon. This paper connects the observed challenges to the literature review and proposes the Systems Thinking methodology as a possible solution.

III. Challenges and Opportunities

The company requires a mix of known and unknown knowledge in technology and market for the front-end innovation project. The user needs are unknown, while the consumer of hydrogen can vary in domain and location. The company focus is currently to *gain knowledge of the enabling technology and investigate potential market opportunities*. In this paper, we focus on the concept for providing energy to an offshore oil and gas production platform on the Norwegian Continental Shelf (NCS).

The Norwegian Research Council and the company are funding the project. The priority of the company is to *prove the business case* to enable commercialization. The company perceives the *total cost of ownership*, consisting of the operational expenditures (OPEX) and capital expenditures (CAPEX), as the main drivers for a potential customer.

The Norwegian Government has a high focus on initiatives for reducing CO_2 emissions in the offshore oil and gas domain. They establish *funding opportunities* to support such initiatives, and they are stimulating field operators to reduce CO_2 emissions by regulating a *CO_2 tax*. Due to the Norwegian Government's responsibility towards the Paris Agreement, the CO_2 tax will probably rise in the near future.

IV. The Systems Thinking Methodology Applied

Systems thinkers view most systems as living (open) systems, moving towards order and complexity [12]. The founder of general systems theory, Ludwig von Bertalanffy, introduced the terminology and world view in the 1940s [13]. Systems theory is a scientific approach to understanding all types of systems, from biological and ecological systems to conceptual systems.

Systems thinkers claim systems can only be understood in context of their environment. The system context is one of the main principles of a system's behavior, and provides an understanding of the openness of the system [12]. The importance of understanding the system's context is also a fundamental principle in systems engineering [2].

A. System Boundaries

Deep Purple can be viewed as a living (open) system. There are three variables that come to play when we investigate an open system [12]: the *controllable variables*, the *uncontrollable variables* we can *influence* and the uncontrollable variables we cannot influence but will have to *appreciate*.

Fig. 3 shows the openness of Deep Purple. We identified as influencing variables within the system's environment: potential customers (such as the field operator), the offshore wind park operator, the authorities that

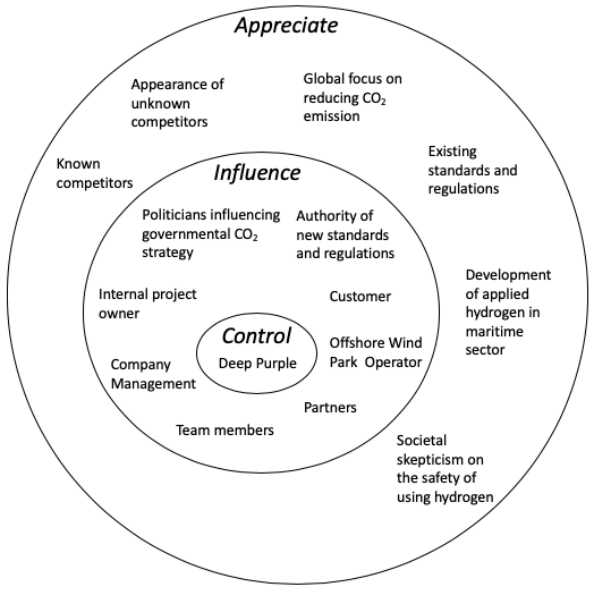

Fig. 3. Context diagram of Deep Purple

develop new standards and regulations that may apply for hydrogen production offshore, potential partners of relevant technology (such as fuels cells and electrolyzers), the project team, politicians that act upon the governmental strategies, the internal project owner within the company, and company management.

Further out in Deep Purple's environment we find the uncontrollable variables that the project can only appreciate. The source to the original idea of Deep Purple: the global focus on reducing CO_2 emissions due to the challenge of global warming is one of these variables. The hydrogen market offshore is under development and get higher and higher focus within the industry. The probability of emergence of unknown competitors is high.

Other uncontrollable variables relevant for Deep Purple are existing standards and regulations for operations on the NCS (including wind farm operation and the use and storage of hydrogen). The level of maturity of applied hydrogen in the maritime sector, as well as the hydrogen grid onshore, is also important variables that may affect Deep Purple. However, the company probably cannot influence it.

Social skepticisms on the safety related to use and storage of hydrogen is another challenge for Deep Purple. Unfortunately, hydrogen has a bad reputation in the society due to accidents like the Hindenburg disaster. This skepticism needs attention when considering the use and social acceptance of Deep Purple. Communication of safe use and storage of hydrogen in Deep Purple, the risks and benefits, is probably a good approach towards the society to mitigate this skepticism.

To get a further understanding of the front-end innovation project's behavior, we need to understand *what* the stakeholders do, *how* they do it and most importantly *why*.

B. Stakeholders and their Interests

Stakeholders in the influence sphere will need to take the best choices for the front-end project to drive it forward. Understanding the stakeholder's interests, why they do what they do, are of high importance in order to affect the choices they make. After all: "*The world is not run by those who are right. It is run by those who can convince others they are right*" [12] p37.

The field operators on the NCS are encouraged by the Norwegian Government to reduce CO_2 emissions and provide CO_2-free alternatives for oil and gas production[1]. Table 1 shows the main stakeholders for the Deep Purple project and their interests.

The Norwegian Government has a high focus on CO_2 reduction, especially within the oil and gas domain. Influencing the right *politicians* may help to find collaboration partners and be beneficial for further funding of Deep Purple.

Table 1. Stakeholders and their interests

Stakeholder	***Interests (why)***
Politicians influencing the governmental CO_2 strategy	Oil and gas actors contributing to CO_2 reduction (support the Paris Agreement)
Internal project owner	Proven business case (to enable commercialization)
Company Management	Customer satisfaction and sustainable solutions (to win more contracts and strengthen reputation)
Team members	Gain knowledge on hydrogen technology and new market opportunities (expand experience and contribute to sustainable solutions)
Authority of new standards and regulations	Safe and sustainable use of hydrogen technology offshore
Partners	Collaborate with enabling actors in the industry (to enter new market opportunities)
Offshore wind farm operator	High availability of the offshore wind park (provide the power that the consumer need at the time they need it) Sustainable solutions (to be in accordance with its main objective)
Customer (field operator)	Total Cost of Ownership (to stay compatible) CO_2-free stable energy to their installation (safe operation without CO_2 emission fee with high availability)

The *internal project owner* wants to prove the business case of Deep Purple, to enable commercialization. Relating user needs to the business case of Deep Purple may help to convince both internal project owner and potential customers of the impact that Deep Purple has on the total cost of ownership. *Company management* is concerned with company profit (getting more contracts) and strengthening the company reputation on sustainability. The main purpose of Deep Purple is to provide a more sustainable solution. A clear communication of how Deep Purple works and how this relates to total cost of ownership may help to strengthen the project's position at top management.

The project manager handpicked *team members* for the project. The interest of each of the team members probably varies, however they all share a common interest in gaining knowledge on sustainable solutions. The possibility of gaining knowledge and experience during the front-end innovation project might provide them with valuable competence for future projects within a potential new market domain for the company. Handpicking team members is probably worth the effort, to ensure that the project has the relevant expertise and the interests within this new market segment.

Regulation authorities strive for safe and sustainable operation of hydrogen in the maritime and offshore domain. Looking towards existing standards and regulations, and continuous communication with regulation authorities may help to find the operational challenges and opportunities provided by future regulations. Sustainable innovations in this

[1] It might seem like a contradiction that oil and gas operators are striving to reduce CO_2 emissions, when their main purpose is to produce oil and gas that will indirectly lead to more CO_2 emissions. The Norwegian Government is still relying on oil and gas production, and this will probably be the case for many years to come. However, reducing CO_2 emissions from the production facility itself will contribute to a more sustainable oil and gas production.

domain may as well lead to adjustment of existing standards and regulations and form the future ones.

Providers of fuels cells and electrolyzers will probably be interested in *collaboration and partnership* with the front-end project, as they might see this as a possibility to enter a new market. Such providers of typical "green solutions" will probably see the benefit of adding their technology and experience into the oil and gas domain due to the governmental focus on reducing CO_2 emissions offshore.

Throughout the year, the offshore wind will vary and hence provides a variable and unpredictable source of power to the production platform. The main interest for the *wind farm operator* is to provide power to the consumer with high predictability. Being a provider of renewable energy, they should also be interested in providing sustainable solutions to the energy consumer.

The production platform, owned by the *field operator*, is the consumer of the off-grid power. Their interest is access to stable CO_2-free power for optimal oil and gas production. The field operator's interest is to operate the production platform according to relevant rules and regulations in a safe manner, and the total cost of ownership for Deep Purple.

C. *Graphical Presentation of the User Needs*

Utilizing Systems Thinking tools, such as a systemigram, may benefit the project team with the purpose of communicating user needs towards stakeholders. The systemigram is a graphical presentation of thoughts intended to be used for communication [14]. Salado and Nilchiani [5] stated that the tool is effective for identification of stakeholders within engineering teams developing earth observation space systems. Sauser et al. [15] also stated the effectiveness of the systemigram when sharing different stakeholder perspectives and thoughts in development of a definition for resilience in maritime homeland security.

Fig. 4 shows a systemigram of Deep Purple. The figure aims to inform how the user needs relate to the purpose of the Deep Purple. The systemigram elements are categorized into the main focus elements in the sweet spot of innovation (Fig. 1); human (users and their needs), technology and business.

In the upper left corner of the figure, we find the system of interest: Deep Purple. In the lower right corner, we find the main goal of Deep Purple that is to reduce CO_2 emissions. The mainstream (bold font) describes the main purpose of Deep Purple: *Utilize new technology in combination with existing technology to produce off grid stable CO_2-free power to achieve a reduction of CO_2 emissions.*

The oil and gas platform are the operational user of Deep Purple, that needs reliable access to off grid stable CO_2-free power for optimal oil and gas production. The field operator owns the oil and gas platform and is a potential customer that needs solutions for reducing CO_2 emissions. The Norwegian Governments is in need of CO_2-free solutions, and the Paris Agreement relies upon Governments to initiate incentives to achieve reduction of CO_2 emissions.

The benefit for the field operator is continuous access to stable CO_2-free power, independent of variations in offshore wind. The hydrogen subsea storage will reduce the size of the wind farm, which affects the total cost of ownership for the field operator positively. The funding possibilities and CO_2 tax set by the Norwegian Government will also affect total cost of ownership positively.

It should be noted that Fig. 4 does not visualize the usage of Deep Purple for the life cycle phases related to installation, maintenance, replacement nor retirement.

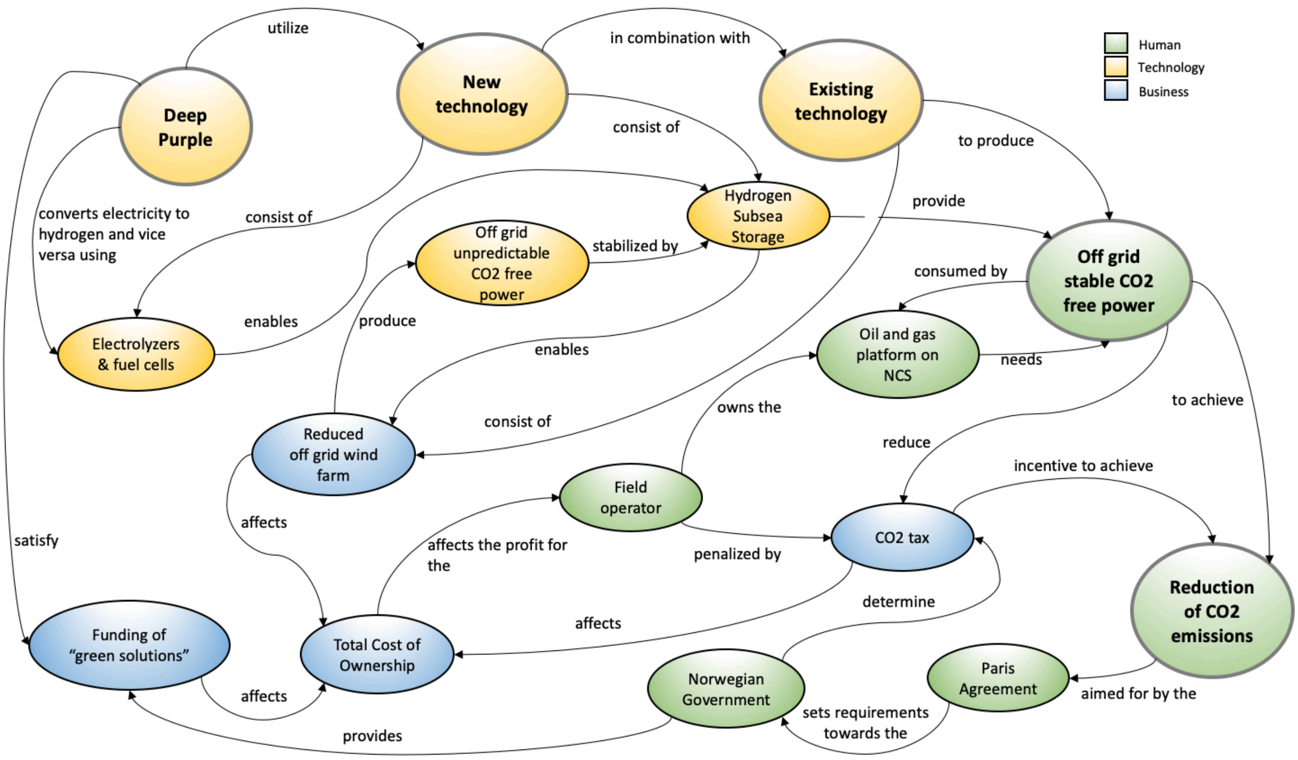

Fig. 4. Systemigram of Deep Purple

D. Possible Leverage Points

The Paris Agreement aims to reduce CO_2 emissions to prevent global warming. The systemigram in Fig. 4 focuses on reduction of CO_2 emissions as the main purpose of Deep Purple, driven by the Paris Agreement. The benefit of Deep Purple concerning total cost of ownership for the field operator depends mainly on the CO_2 tax and funding possibilities given to "green solutions" provided by the Norwegian Government. This indicates that *the future changes in the Norwegian Government's CO_2 strategy will have a large impact on the business case for Deep Purple*

Another interesting force that acts upon the system is the future of oil and gas production. The systemigram focuses on application of Deep Purple towards an offshore production platform. The global focus on reducing the use of fossil fuels is high, and renewable energy sources are a hot topic these days. The company is a provider of subsea systems and installations services to the oil and gas domain. The *future of the oil and gas domain will affect the application of Deep Purple*, as well as the core business of the company.

The systemigram provides information on how the production platform relates to Deep Purple and the benefit it gets from this collaboration. Off grid wind farm as a power source to production platforms is a new concept in development by field operators today. If the field operator owns the wind farm, the systemigram shows how total cost of ownership help to meet the user needs of the field operator. If the field operator does not own the wind farm, *the benefit of Deep Purple for the wind farm is unclear*.

At this point in time, the project team has not yet had the possibility to perform user research of the external stakeholders. As the project progresses and establishes collaboration with external stakeholders, the next step will be to *investigate the user needs of the various stakeholders further to validate the assumptions made so far*.

V. Evaluation

A. Developing the Graphical Presentations

The researchers developed the graphical presentations (Fig. 3, Fig. 4) based on discussions with the other team members. The development was an iterative process. The context diagram and stakeholder table were established in a few hours. The systemigram took approximately two weeks to develop and required several iterations to mature and reach a satisfactory level.

We found it challenging to develop a systemigram given the design rules presented in [14]. This might be due to several reasons. There were several views of the system that we unsuccessfully tried to include, such as the role of competing and existing technology (cable to shore and gas turbines) and how this relates to Deep Purple. We also found it difficult to include other life cycle phases than the operational life cycle phases, such as installation, maintenance, replacement and retirement. We found that by including too many relations into the systemigram, we failed to bring a clear message through. By selecting a set of relations and views, we were able to provide a message with a clearer meaning.

B. Testing of the Graphical Presentation

The project manager tested out the graphical presentations in two separate meetings with external stakeholders. The test was performed with a black & white version of the systemigram, without categorizing into humans, technology and business. The external stakeholders were unfamiliar with the Deep Purple system prior to the meeting. One meeting was with a potential collaboration partner of fuel cells and electrolyzers systems. The other meeting was with a consultancy for business strategy. In both meetings, the graphical presentations got good feedback, especially the systemigram. The meeting participants were unknown with systemigrams beforehand and found the systemigram to be fascinating and informative. The project manager also found the systemigram to enable an intuitive and systematic communication of the purpose of Deep Purple. The internal concept report to describe the purpose of Deep Purple for the offshore oil and gas platform on the NCS applied the systemigram.

VI. Conclusion and Future Research

In this paper, we pursued *the applicability of the Systems Thinking methodology as a potential early validation method of user needs* in the front end of innovation for a real case in the offshore SoS.

The case is adding an off-grid renewably energy system for offshore consumers, called Deep Purple. The industrial front-end innovation project is a sustainable initiative for a global provider of subsea systems and installation services in the oil and gas domain. The researchers have been part of the industrial project team. They applied Systems Thinking methodology, developed context diagram and systemigram of Deep Purple and tested it out on external stakeholders.

We found it challenging and time-consuming to develop a systemigram with a clear message and according to the design rules given in [14]. The systemigram shows the operational view of the system, however we were unable to show other important life cycle phases for the user, such as installation and maintenance. Adding more systemigrams showing the missing relations and views can most likely solve this.

Analyzing the openness of Deep Purple using the context diagram and the stakeholder interest table indicates to be a low-effort and powerful tool to analyze stakeholders and their needs. Developing a systemigram indicate to be a slower but helpful tool to further understand the complexity of Deep Purple and its context. The systemigram also indicates to be a good commination tool towards external stakeholders to communicate the purpose of Deep Purple.

The Systems Thinking methodology indicates to be helpful in the early phase of systems engineering to provide understanding of stakeholder needs and manage complexity. Further research is needed to conclude on how effective it is for early validation of user needs in the front end of innovation.

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REFERENCES

[1] P. A. Koen *et al.*, "Fuzzy Front End: Effective Methods, Tools, and Techniques," *Ind. Res.*, 1996.

[2] INCOSE, *Systems Engineering Handbook*, 4th ed. Hoboken, New Jersey: Wiley, 2015.

[3] K. Eling and C. Herstatt, "Managing the Front End of Innovation—Less Fuzzy, Yet Still Not Fully Understood," *J. Prod. Innov. Manag.*, vol. 34, no. 6, pp. 864–874, 2017.

[4] P. Koen, G. Ajamian, and R. Burkart, "Providing clarity and a common language to the 'fuzzy front end,'" *Research Technology Management*, pp. 46–53, 2001.

[5] A. Salado and R. Nilchiani, "Contextual- And behavioral-centric stakeholder identification," *Procedia Comput. Sci.*, vol. 16, pp. 908–917, 2013.

[6] M. Kjørstad and K. Falk, "Innovating in the Offshore Sector; Applying Systems Thinking for Decision-Making in the Fuzzy Front End (unpublished)," *INCOSE Hum. Syst. Integr. 2019*, 2019.

[7] D. J. Snowden and M. E. Boone, "A Leader ' s Framework for Decision Making," *Harv. Bus. Rev.*, vol. 85, no. 11, pp. 68–76, 2007.

[8] T. Brown, "Design Thinking," *Harv. Bus. Rev.*, vol. 86, no. 6, pp. 84–92, 2008.

[9] T. Kelley and D. Kelley, *Creative Confidence: Unleashing the creative potential within us all*. London: William Collins, 2015.

[10] M. Kjørstad, K. Falk, G. Muller, and J. Pinto, "Early Validation of User Needs in Concept Development: A Case Study in an Innovation-Oriented Consultancy," *Int. Hum. Syst. Eng. Des. Conf. 2018*, vol. 876, pp. 54–60, 2019.

[11] G. J. Muller, "Systems Engineering Research Methods," *2013 Conf. Syst. Eng. Res.*, vol. 16, no. Procedia Comput. Sci., pp. 1092–1101, 2013.

[12] J. Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity*, Third. Burlington: Elsevier Inc., 2011.

[13] L. von Bertalanffy, "The History and Status of General Systems Theory," *Source Acad. Manag. J. Gen. Syst. Theory*, vol. 15, no. 4, pp. 407–426, 1972.

[14] J. Boardman and B. Sauser, *Systems Thinking - Coping with 21st Century Problems*, 1st ed. Boca Raton: CRC Press, 2008.

[15] B. Sauser, M. Mansouri, and M. Omer, "Using Systemigrams in Problem Definition : A Case Study in Maritime Resilience for Homeland Security," *J. Homel. Secur. Emerg. Manag.*, vol. 8, no. 1, pp. 1–10, 2011.