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Leveraging design thinking in MBSE: mitigating data and information uncertainties – an integration model approach

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Abstract

The evolving needs of customers and stakeholders necessitate the collaboration of diverse system elements within a cyber-physical, socio-technical network. Socio-technical systems are characterized by numerous complex interdependencies as well as by endogenous and exogenous influences. A key issue that developers must address is the mitigation of data and information uncertainties. The authors introduce an approach that operationalizes Design Thinking as a supporting sufficient condition within the context of designing system models in the realm of Model-Based Systems Engineering.

Keywords: model-based systems engineering (MBSE), design thinking, systems engineering (SE), systems thinking, systems design

1. Introduction

The perception of deficiencies and the resulting desire to correct these deficiencies is an inherent pattern of human behaviour (Metz-Göckel, 2022). According to Hubka (1973), these perceptions are human needs. Humans strive to satisfy these needs and develop their potential (Gräßler and Oleff, 2022). Based on this basic idea of the concept of needs, it could be stated that customer needs define the starting point for developing new and innovative solutions for products to eliminate the deficiency identified in the needs. They also play a prominent role in the evolution of existing solutions. Furthermore, Ulrich *et al.* (2020) see the recognition of customer needs and the rapid development of appropriate products as a crucial aspect for the economic success of most companies.

Allen *et al.* (2021) note that using networked and intelligent technologies means many new products are no longer stand-alone islands with self-contained functions. This indication also leads to a shift in the focus of the development goal to the services and performances of the emerging network, which consists of various complex systems working together in an interactive and multidisciplinary manner (Gadzo *et al.*, 2023). Satisfying customer needs in such socio-cyber-physical systems must be considered more holistically. In addition to the physical product, other factors, such as fostering users' emotional and hedonistic experiences, can contribute to added value (Allen *et al.*, 2021). These human-centered aspects must be considered when developing efficient and effective approaches to support the product development process. Thus, human-centered aspects must also be ensured in developing the individual systems of such an overarching system (Krause and Heyden, 2022). The Design Thinking approach puts the customer in the foreground, focuses on building empathy with users, observes user behaviour, and draws conclusions about what people want and need (Levy, 2017). It thus provides the means to address the challenges arising from the human-centered aspects. Looking at the whole and identifying patterns and interrelationships, as well as gaining insight into how to structure these interrelationships effectively and efficiently is made possible by System Thinking (Mella, 2012). It is an essential element of Systems

Engineering, which is analytical and data-driven (Greene *et al.*, 2019), and its model-based offshoot, Model-Based Systems Engineering (MBSE). Both approaches,
Design Thinking and System Thinking in the context of Systems Engineering, are complementary to successfully address the challenges described above and to provide a holistic and human-centered view of user and stakeholder needs (Kaur and Craven, 2022). Hehn *et al.* (2020) have already noted that Design Thinking can extend the requirements engineering toolbox. Darrin and Devereux (2017) argue that the techniques of Design Thinking, in addition to their focus on customer-centered interaction, also have an affinity to Model-Based Systems Engineering, and (Manoury *et al.*, 2022) also see people as the driving force in Model-Based Systems Engineering. Therefore, this paper wants to address the following research question:
How can Design Thinking be used in the context of MBSE and related systems modelling to reduce uncertainties in data and information?
The paper is organized as follows: Section 2 explains the research approach, followed by the relevant theoretical background in Section 3. Section 4 gives a brief overview of related work. Section 5 describes the approach in general, and Section 6 illustrates the described approach with a initial use case. Finally, a conclusion and an outlook are given.

2. Research approach

The present contribution uses the design methodology based on Hevner et al., which initially evolved during research on the Information Systems Research Framework (Hevner *et al.*, 2004). The authors used this framework and the cycles described in detail in Hevner and Chatterjee (2010) to develop a model for answering the research question. The three pillars of Environment, Design Science Research and Knowledge Base form the foundation, and are complemented by the Relevance Cycle, the Rigor Cycle, and the Design Cycle. The investigation of the environment, which establishes the parameters of the problem domain, served as the foundational basis, leading to the derivation of the research question. To address this research question, a model approach was developed that integrates design thinking into the systematic and methodical approach of Model-Based Systems Engineering. The scope of the present work is limited to the development of an integration model approach, focusing solely on the initial phase of the procedure depicted in Figure 1.

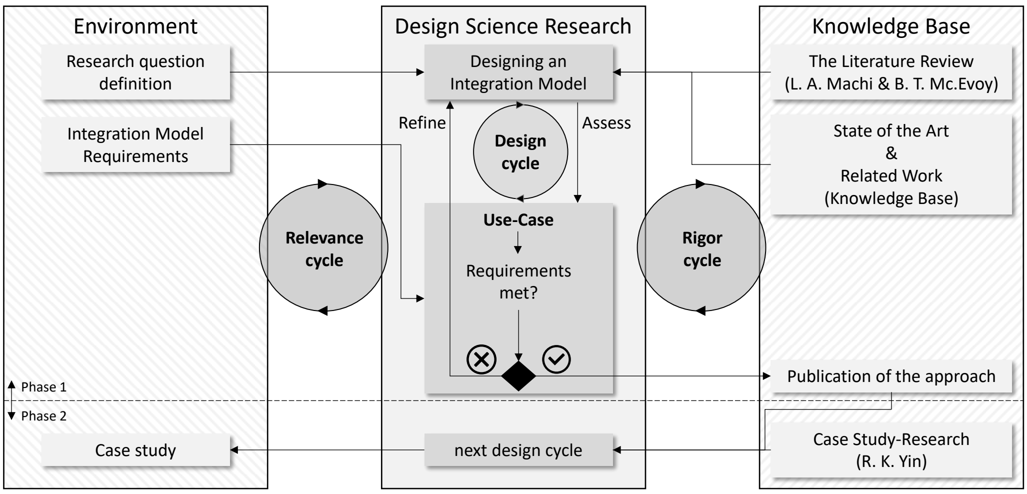

Figure 1. Research approach according to (ibid)

The foundation for defining the research question and developing the approach was a systematic literature review, following the six-step process outlined by Machi and McEvoy (2016). A search matrix was established, which was subsequently transformed into a search string and inputted into the Scopus database. The utilized search matrix is illustrated in Figure 2. The subject area was limited to engineering and computer science. As a result, a total of 264 articles were identified, and a multi-stage selection process was employed to review their content relevance. Papers were classified as relevant if they related

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to one of the following subject areas: Fundamentals of design thinking; design thinking methods; integration of design thinking in systems engineering and MBSE; integration of design thinking and systems thinking; use of design thinking for problem solving. In the first step, the topic, keywords, and the abstract were reviewed. In the second step, research questions, conclusion and the description of the solution were assessed. Finally in the last step, a comprehensive review of the source was conducted and supplemented with in-depth research through recursive source tracking, resulting in the identification of 48 papers. These papers serve as a foundation for the state of the art, described in Section 4, and represent together with the methodology, used for the literature review the content of the Knowledge Base pillar for the first phase. The primary emphasis lay in establishing a foundation conducive to the development of an integration model. The identified literature also forms the basis for the definitions provided in Section 3. The following requirements were established to evaluate the model approach within the context of the use case in the Design Science Research pillar:

1. The integration model shall facilitate the alignment of the system model with the genuine needs of the users, taking into account perceived and actual needs.
2. The integration model shall support in refining the system model, leading to a reduction in uncertainties.
3. The integration model shall facilitate the identification and mitigation of sources of uncertainty concerning data and information.
4. The integration model shall enhance the level of detail in data and information, thereby promoting coherence.

	AND		
OR	Design Thinking	support	MBSE
		enhance	Model-based Systems-Engineering
		improve	Systems Engineering
		and	Modelling
		in	

Figure 2. Search matrix for the literature review

3. Background

3.1. Uncertainties

The consideration of uncertainty plays a prominent role in various facets of human endeavours, as dealing with them is challenging. Consequently, this term encompasses a diverse range of ideas and concepts (Thunnissen, 2003). In order to provide a foundational explanation of the term and to formulate a general definition that transcends disciplinary boundaries and can be employed as a taxonomic foundation in diverse fields, (ibid) describes uncertainty as susceptibility to coincidence or accident, as ambiguity, as a lack of certainty, and as something that remains unknown or unknowable. An individual experiences this sense of uncertainty, for instance, when they find themselves incapable of making precise predictions (Milliken, 1987) or when they struggle to discern relevant from irrelevant data (Gifford *et al.*, 1979). De Weck *et al.* (2007) perceive uncertainty as an elusive concept that encompasses, on one hand, the potential for erroneous assumptions to arise during development and, on the other hand, the presence of unknown factors whose influence on the future success of a product is anticipated. Consequently, uncertainties significantly impact the design of novel products and systems (Dym *et al.*, 2005). Pendzik *et al.* (2023) perceive development processes as fundamentally characterized by uncertainty. This characterization is also linked to the fact that development teams work concurrently on various purposeful artifacts, which are subsequently aggregated to a beneficial overall solution. Given the interdependencies among these tasks, numerous interfaces within information flows can result in uncertainties concerning information availability (Paetzold, 2022). Consequently, Gifford *et al.* (1979) observes a distinct inverse correlation between the concepts of uncertainty and information. Within the scope of this paper, the primary focus lies on epistemic uncertainties, as these can be mitigated through problem related knowledge discovery (Walker *et al.*, 2003). In contrast, aleatory uncertainties are not further

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considered, as these random-based uncertainties are not systematically reducible. Based on the conceptualization by Paetzold (2022), uncertainties are understood as encompassing discrepancies, gaps, inconsistencies, and incompleteness within data and information (D&I), as well as their corresponding flows. Gaps include missing connections and relationships between different D&I, but also missing information about specific aspects such as the definition of the system context and considering all relevant context elements in which a system to be developed is considered. If D&I related to a system element are available but are incompletely described and documented, such as the absence of properties within defined flows between two elements, this circumstance is considered as an incompleteness of D&I. Finally, in the context of information inconsistencies, they can be seen as different D&I giving the same information about a specific aspect or element simultaneously and contradicting each other. Thus, they can also be understood as ambiguity.

3.2. Design Thinking

To establish a foundational understanding of Design Thinking, a concise examination of the term "design" will be presented initially. The term design is defined as the process of defining the architecture, components, interfaces, and other features of a system or component (Adams, 2015). Ulrich *et al.* (2020) incorporate both engineering design and industrial design under the term design. The two aspects can be considered complementary but have different emphases (VDI, 1986). In general, engineering design can be understood as the sum of all work steps from the product idea to the production of the manufacturing equipment (Feldhusen and Grote, 2013). However, the emphasis primarily lies on the technical functionalities in engineering design, whereas industrial design focus on the interaction with individuals (VDI, 1986). Dym *et al.* (2005), on the other hand, summarize these two aspects in their interpretation under the term engineering design. The authors see engineering design as a systematic, intelligent process in which designers develop, evaluate, and specify concepts for devices, systems, or processes. The form and function of these concepts meet the goals of the customer or the needs of the users and at the same time fulfil a certain number of constraints. These conceptual definitions are all very concrete and placed in a technical context, making them particularly valuable for understanding in the context of MBSE. However, in order to understand Design Thinking from a more holistic perspective, the authors use a more abstract variant of Simon (1978), in which design means to develop ways of acting that aim to transform existing situations into preferred situations. This definition also emphasizes the linkage between the initially described concept of needs and design.
The term Design Thinking is discussed in detail in many works and is interpreted and applied in different ways (Tekaat *et al.*, 2021). Ney and Meinel (2019) answer the question of what Design Thinking is in detail in their work and consider it as a dynamic interaction of heterogeneous teams that let Design Thinking take place in an innovation space and follow a process. They use the comprehensive interpretation of Johansson-Sköldberg *et al.* (2013) as a foundation. Figure 3 illustrates a summary of the concept of (ibid) and briefly summarizes the individual views, which are based on two overarching discourses which differ in their perspective.

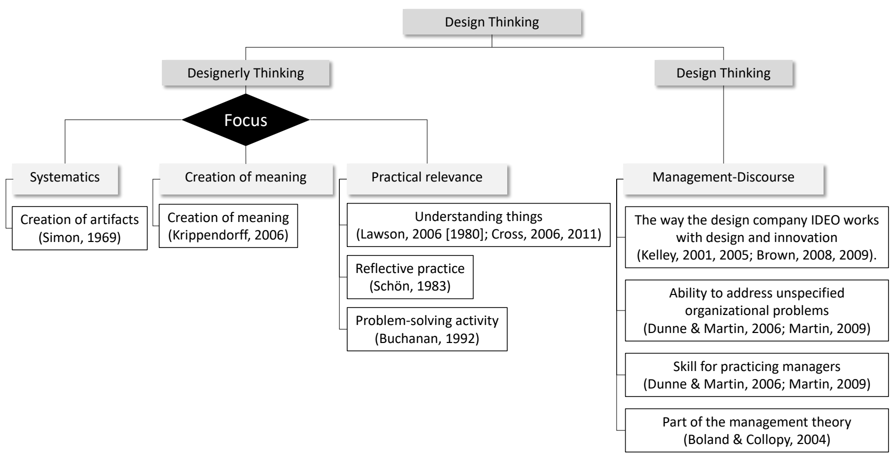

Figure 3. Design Thinking views according to Johansson-Sköldberg *et al.* (2013)

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One discourse focuses on an academic view of design thinking, for which the term "designerly thinking" is used. The second discourse takes place in a non-academic context, without any significant scientific design background. The second discourse includes the well-known interpretation of Design Thinking according (Brown, 2008), in which Design Thinking is seen as a human-centered approach to innovation that draws from the designer's toolbox to integrate the needs of people, the possibilities of technology, and the requirements of business success. It can be concluded that the human-centered aspect plays a prominent role in Design Thinking (Di Russo, 2016). Dumitrescu *et al.* (2021) see in Design Thinking the possibility to reduce the complexity of development tasks and to increase their manageability, emphasizing a direct integration into engineering. Based on these interpretations, the following characteristics of design thinking can be identified, which are relevant in the context of this paper: Problem solving, reducing complexity, understanding, observing, human-centered and, according to Camacho (2018) system-oriented.

3.3. Systems Thinking, Systems Engineering, MBSE

INCOSE (2015) defines MBSE as a formalized application of modelling to support system requirements, design, analysis, verification, and validation activities. The application begins in the conceptual design phase and continues through development and later life cycle phases. Delligatti (2013) describes the basic elements of MBSE in a descriptive way using the following three pillars, thus clarifying the formalization: The initial pillar entails a language that establishes the elements and relationships that can be defined within the model. The second pillar, known as the method, outlines the utilization of the language for constructing a system model. Finally, the third pillar of MBSE is the tool, which furnishes a user interface to streamline and facilitate the process of model building, offering support along the way. The contribution of Gadzo *et al.* (2021) initially examine, the individual terms "systems engineering" and "model" separately before merging them in a subsequent step to form a comprehensive understanding of the term MBSE. According to Dick *et al.* (2017), the term *model* is understood as an abstraction of a system. This abstraction focuses on those aspects of a system that are relevant for a defined consideration. In contrast, other aspects are neglected, whereby models separate the essential for a task from non-essential aspects (ibid.). Generally, models play an important role in managing complex systems and in organizing, processing, exploring, and finding information about large systems (Ramos *et al.*, 2012). Systems Engineering on the other hand, is considered as an interdisciplinary approach that enables the implementation of successful systems by focusing on the definition of customer needs and the required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and validation, always taking into account the overall problem (INCOSE, 2015). According to (ibid), there are certain characteristics of Systems Engineering that result from the various definitions and characterize the term: Interdisciplinary, iterative, holistic, socio-technical and, above all, the underlying systems thinking.

Systems Thinking is therefore an important component of Systems Engineering and MBSE. It describes a way of thinking that makes it possible to understand and design complex phenomena such as systems (Lindemann, 2009). The essence of Systems Thinking is the consideration of the overall task and the overall process while working on individual subtasks or sequential work steps, which promotes the achievement of a favourable overall solution while optimizing the individual assemblies or sub-steps (Feldhusen and Grote, 2013). Furthermore, Systems Thinking is even estimated as one of the most powerful tools of knowledge and understanding, because it teaches us to develop coherent and meaningful models of the world, whereby overall social improvements and design possibilities arise (Mella, 2012). The holistic view based on models is also emphasized in Lindemann (2009) and it is further pointed out that Systems Thinking, and the application of models contribute to mastering the complexity of the systems to be developed, especially when it comes to socio-technical systems. An illustrative representation of the interrelationships among Systems Engineering, Systems Thinking, MBSE, and their associated modelling is presented in the Systems Engineering concept proposed by Haberfellner *et al.* (2019). Figure 4 depicts a simplified version of the concept, accentuating these three aspects.

A fitting conclusion to Section 3 is drawn from Palambros (2022), who perceives the contemporary systems designer's role as a fusion of the traditional functions performed by both systems engineers and product designers. The modern systems designer applies what is called systems design thinking, which

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integrates Systems Engineering, Systems Thinking, and Design Thinking (Palambros, 2022; Greene *et al.*, 2019). In the subsequent section, an in-depth analysis of Systems Design Thinking is presented as an integral part of the state-of-the-art description and related work.

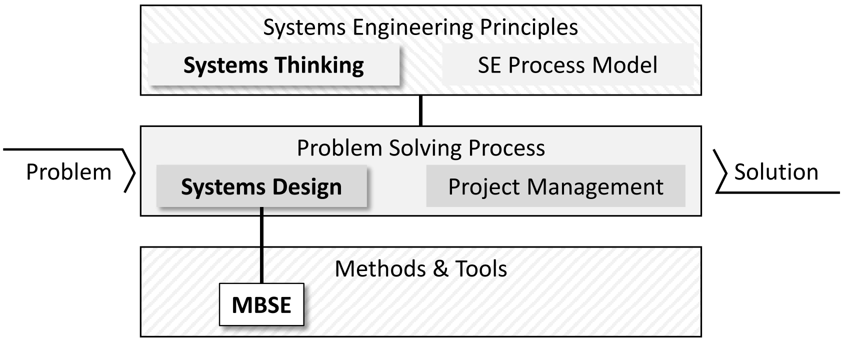

Figure 4. The simplified Systems Engineering concept based on Haberfellner *et al.* (2019)

4. Related work

A fundamental aspect of the use of Design Thinking is the way of thinking within a defined and mostly iterative process. Dorst (2011) examines the way in which fundamentally different ways of thinking are described in formal logic, in order to get to the heart of design thinking. He describes the thinking patterns of induction, deduction, and two forms of abductive thinking using an equation in which a desired value is the sum of the applied working principle and a subject. Abductive thinking is a concept developed by Charles Sander Pierce in the 19th century in which perception plays an important role. It can be understood as thinking in new and different perspectives and about future possibilities (Tschimmel, 2012) . Another important principle is the combination of convergent and divergent thinking (Brenner and Uebernickel, 2016). The design thinking double diamond of the British Design Council (2005), as presented for example in Hehn *et al.* (2020) is based on the divergence-convergence model of Banathy (1996) and illustrates the interplay between divergent and convergent thinking. Thereby, it is either necessary to open up a large space through divergent thinking e.g., when exploring user needs and the environment to create the largest possible space for problem definition and later solution finding, or when brainstorming for a defined problem. Convergent thinking is needed, for example, to condense the collected information into possibilities for the identified needs (Hehn *et al.*, 2020). In addition to the double diamond process model, there are other approaches to the Design Thinking process. Some of the most well-known models in this context include the 3-I model and the HCD model by IDEO, the model by the Hasso-Plattner Institute, and the Service Design Thinking (SDT) model by Stickdorn and Schneider (Tellioglu, 2016). The 3-I model consists of the phases Inspiration, Ideation, and Implementation, while the HCD model focuses on Hearing, Creating, and Delivering. The model by the Hasso-Plattner Institute, on the other hand, comprises the phases Understand, Observe, Point of View, Ideate, Prototype, and Test, while the SDT model consists of the four phases Exploration, Creation, Reflection, and Implementation (ibid).An explanation of the models can be found in Tschimmel (2012). Furthermore, the current model of the Hasso Plattner Institute of Design at Stanford should be mentioned (Alhazmi and Huang, 2020), which consists of the steps Emphasize, Define, Ideate, Prototype and Test (Plattner, 2010). This model also emphasizes the iterative nature, both at the process level and within the individual steps.

Greene (2019) developed an integrated framework for Systems Engineering, Systems Thinking, and Design Thinking, which describes that systems engineers use a human-centered approach to develop complex systems, while product designers use systematic and analytical behavior in their design activities. The Systems Design Thinking framework suggests that Design Thinking and Systems Engineering can be complementary, and thus the work provides fundamental insights for exploring the use of Design Thinking in Systems Engineering. Tekaat *et al.* (2021) summarize in their systematic literature review Systems Design Thinking as an interdisciplinary and collaborative approach that combines divergent and convergent thinking strategies by integrating customer needs using empathy and creativity on the one hand and using a systematic and methodical Systems Thinking approach on the other to structure

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and process content. Furthermore, Durantin *et al.* (2016) see design thinking as assistance to better envision the system, while Systems Engineering grounds the system. The authors also consider the two methods to be applicable alongside and complementary to each other, as Design Thinking is well suited to guide and extend divergent thinking but lacks tools to collect and organize the results into a content structure. In contrast, Systems Engineering benefits from structuring content, but lacks the means to incorporate diverse and alternative content. The basic idea and essence of the integration model presented in this paper is derived from these statements and remarks.

For the development of an integration model based on these insights, the model developed by Tekaat *et al.* (2019) for the integration of design thinking in Automotive Systems Engineering was identified as a source of inspiration. The paper addresses the question, which parts of Design Thinking can be integrated along Automotive Systems Engineering to address safety challenges. To answer this question, an integration approach with a focus on safety and security is developed, based on the Design Thinking interpretation according to Brenner and Uebernickel (2016). which in turn is based on the five-step model of the Hasso Plattner Institute for Design at Stanford. The first two phases of the iterative process describe the problem space, the following three phases the solution space of the integration model. The authors also implement the aspects of divergent and convergent thinking in their model. A limitation is that the approach only considers the system design phase within the V-model for safety and security-oriented vehicle development (Tekaat *et al.*, 2019). Furthermore, the problem-solving model of Anders Skoe described in Camacho (2018) is used as an adaptation basis. Like the Design Thinking process model of the British Design Council, it consists of two diamonds, whereas in Skoe's model sub-diamonds appear at different stages and illustrate the change between analytical (convergent) and creative (divergent) thinking. Finally, two aspects are taken up from the work of Tomita *et al.* (2017), which deals with the development of the Structured Design Thinking framework to use it to integrate the unstructured design thinking process and the structured Systems Engineering process. It considers the concept of insight, which is a component of the Structured Design Thinking framework, and states that insight is discovered at each stage of the thinking process and in many cases during the discussion of results, which has an impact on the emergence of iterations. In addition, the framework's placement in the Data-Information-Knowledge-Wisdom (DIKW) model between information and knowledge is considered, as the framework supports knowledge creation.

5. General approach

Before presenting the integration model approach, we would like to examine the research question from a purpose-driven perspective and provide insight into the motivation. The authors aim to develop a methodology for the in-process development and maintenance of holistic system models to support the further development of data and information and their flows in satellite development projects. The focus lies on identifying and mitigating uncertainties associated with data, information, and their flows, as well as facilitating knowledge generation throughout the development process. The goal is to address this issue on various levels, for which a SYSML-based method for transferring and further developing document-based data and information in a model-based development environment was initially designed (Gadzo *et al.*, 2023). the utilization of which is a prerequisite in this paper's context. Based on the literature research findings, the motivation now emerges to develop a procedure model based on design thinking as part of the overall solution. The purpose of the DT-MBSE integration model is to outline the procedure for developers within the methodology at a macro level, independent of modeling language and tool. The implementation of individual steps of the model in a modeling language such as SYSML is not addressed in this article but remains a crucial component of the overall methodology. However, the following explanation will solely focus on the DT-MBSE integration model, which represents the task-specific procedural model of the methodology under development.

The basis of the integration model is a Double Diamond process model adapted from Anders Skoe's problem-solving model. The objective is to combine the strengths of Design Thinking and Systems Thinking within the context of MBSE to effectively address uncertainties in D&I and provide an answer to the research question. The first diamond of the model focuses on identifying uncertainties, while the second diamond aims to mitigate these identified uncertainties. The model also involves three entities that contribute to the respective process steps: the modelling team, the Systems Engineering (SE) team, and the domain-specific development team. Figure 5 illustrates the schematic representation of the DT (Design Thinking)-MBSE integration model. The symbols in the figure indicate the contributions made by each team within the process steps of the respective diamond. Additionally, the figure depicts arrow circles to represent the iterative nature of the process, indicating which steps are covered in an iteration loop. The main task of the modelling team is to construct and maintain the model, requiring proficiency in a suitable modelling language and appropriate tools. However, team members of the modelling team, much like the SE team, possess skills necessary for effective Systems Engineering, particularly systems thinking.

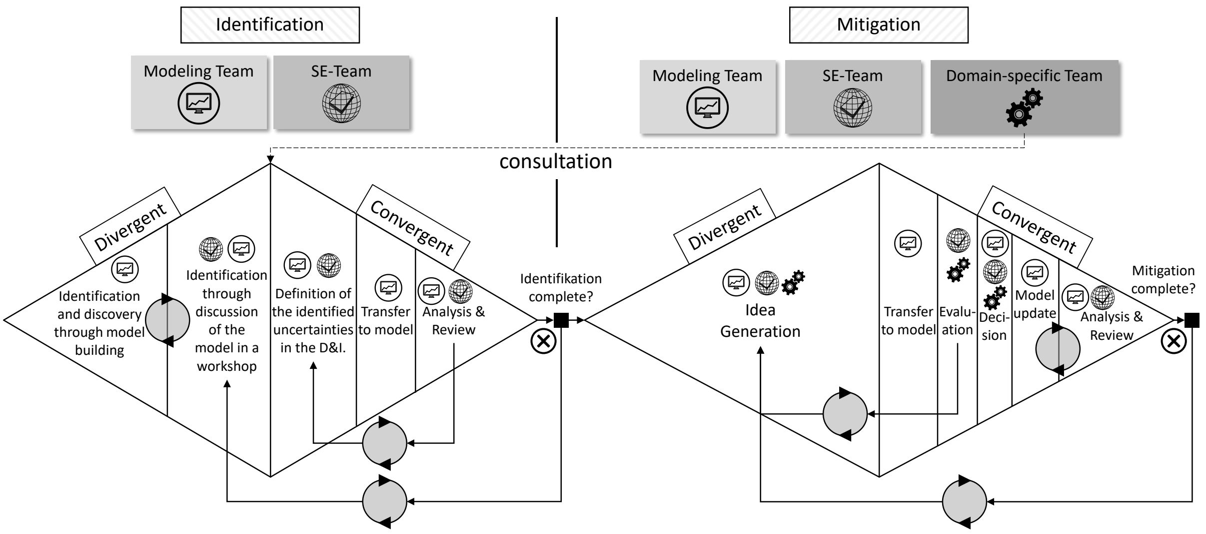

Figure 5. The DT-MBSE integration model

The SE team holds a prominent position within the model and embodies the characteristics of a modern systems engineer, as described by Palambros (2022). They exhibit behaviours that encompass empathy and creativity, while also employing systematic and analytical thinking methods. Domain-specific developers play a crucial role in resolving uncertainties due to their extensive expertise in a specific technical domain. As a result, they are key contributors to the mitigation-process in the right diamond of the process.

The divergent phase of the first diamond consists of two steps, which are iterated as depicted in Figure 5. In the first step, the objective is to identify and uncover uncertainties through the initial construction of the model. This is accomplished by transferring all document-based D&I into an MBSE model, a task carried out by the modelling team. It is crucial to emphasize a holistic view of the system and incorporate systematic and analytical aspects. The systematic and methodical approach employed in this step helps uncover and identify uncertainties. Additionally, creative thinking mechanisms are essential, as this step involves both developing an understanding of the problem at hand and establishing a foundation for the creation of new artifacts. In the second step, a workshop takes place wherein both the SE team and the modelling team participate. Similar to the approach described by Tekaat *et al.* (2019), the initial goal of the workshop is to establish a shared knowledge base regarding the initial situation and to empathize with the situation in the spirit of design thinking. Empathetic aspects are crucial in this phase, as the needs of stakeholders must be considered from various perspectives to uncover additional uncertainties. The work of the teams in the first two steps can be enhanced and facilitated by employing design thinking methods, as documented in the works of Tellioglu (2016), Chasanidou *et al.* (2015), and Alves and Jardim Nunes (2013). Moving into the convergent phase, step three involves defining and transferring the results obtained from the workshop (step two) to the model, a task carried out by the modelling team. Step four entails the analysis and review of the model, with the results being iteratively incorporated back into the definition step. This iterative process leads to a refinement of the definitions of (D&I) uncertainties. The first diamond is then iterated until a satisfactory definition of uncertainties in the D&I within the MBSE model is achieved, considering the perspectives of both teams.

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The described process in the first diamond exhibits similarities to the methodology presented by Hubka and Eder (1992) regarding scientific progress and the historical development of design science. In the initial phase, a model of general design science was established, drawing upon existing knowledge in specific fields as an inductive process. Simultaneously, the design of the whole model was accomplished by assembling existing parts, equivalent to a synthesis. These actions bear resemblance to the first two steps outlined in the integration model. Furthermore, (ibid) explains that model checking through analysis and deduction was conducted, which also aligns with the convergent phase of the left diamond in the integration model. In the subsequent phase, the model was enriched with domain-specific knowledge, obtained from a broad knowledge base that encompassed practical experience and know-how. Examining the right diamond of the integration model in Figure 5, we can also observe similarities between the mitigation of defined uncertainties in the D&I and the second phase described by (ibid). The practice-based knowledge base can be attributed to the domain-specific team entity, while the entire right diamond aims to enrich the model with specific knowledge and thereby mitigate the uncertainties identified in the first diamond. To achieve this goal, collaborative idea generation takes place during the divergent phase, where design thinking methods can be employed as supportive tools. In the convergent phase, these ideas are evaluated, analyzed, reviewed, and iteratively refined using the MBSE model until all identified uncertainties have been successfully mitigated, resulting in satisfactory artifacts. Figure 5 provides a visual representation of the contributions made by different entities in each step and illustrates how the steps are interconnected in an iterative manner.

6. Initial use case

The use case presented in this paper is akin to the support evaluation of Blessing and Chakrabarti (2009) in the prescriptive study and serves as a minimal evaluation based on an initial use case. Subsequently, an application and success validation will be conducted for the entire methodology, as this type of evaluation necessitates further development artifacts of the methodology, such as an ontology and an element library, which are currently under development and will directly support system modeling. The criteria outlined in Section 2 will be refined for the final evaluation of the methodology by making them more specific and incorporating measurable aspects. Additionally, they will be expanded to include further criteria that can then be assigned to an application and success validation. For an initial usefulness test of the procedural model within the prescriptive study, the defined high-level requirements are appropriate. In the following description, the identification phase of the integration model is illustrated using an example of the system context analysis for a payload system in a small satellite mission. Furthermore, two employees from the project, belonging to the systems engineering group and with 2-3 years of professional experience at the time, were involved. They were neither involved in the development of the integration model nor participated in the methodology development. The use case examines the initial application of the integration model within the context of the analysis elements of the method by Gadzo *et al.* (2023). Figure 6 illustrates both the applicability of the process model to the five types of analysis elements of the method and the interdependence of the analysis types. The entire process is fundamentally iterative, as depicted by the arrow circles in Figure 6. For modeling, SYSML was employed as the modeling language and the Cameo Systems Modeler as the tool. The analysis elements from the method developed by Gadzo *et al.* (2023) were utilized and are described accordingly. The initial input for this phase consisted of existing D&I selected for the use case from various sources, which were transformed into an MBSE model.

During the divergent phase, the team deliberated on potential system contexts that might exist but were not documented in the existing D&I. This discussion led to the definition of a new context landscape in the convergent phase. Subsequently, the team analyzed and defined uncertainties related to potential context partners and the flows between the system under consideration and these context partners. This information was integrated into the model. Through further iterations of the process, the team examined possible context structures as well as aggregation and composition relationships that needed consideration. Finally, a white box view of the captured system contexts was created, identifying possible interfaces and missing information on these interfaces. In summary, the iterative process facilitated by the integration model allowed for refinement and improvement of the system context description, as well as initial identification and definition of uncertainties. For instance, the launch-context, which at the

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time had a patchy information landscape in terms of requirements and interface definitions, was clarified. By employing the integration model, sources of uncertainty in D&I were initially identified and prepared for reduction (Rq 3). Additionally, the integration model played a role in refining the system model (Rq 2) and increasing the level of detail of the D&I (Rq 4). However, the evaluation of the first requirement for the integration model could not be verified in this initial assessment, as further development artifacts from the methodology are necessary for this, as described above.

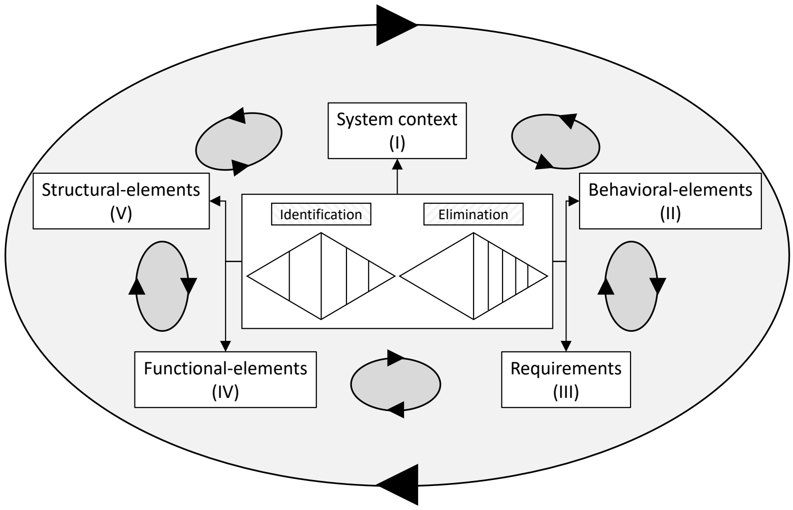

Figure 6. Use of the DT-MBSE integration model in the method of Gadzo et al. (2023)

7. Conclusion

This paper introduces an approach for an integration model aiming to utilize design thinking within the context of MBSE and associated system modeling to mitigate uncertainties in data and information (D&I). The proposed model, termed the DT-MBSE integration model, is founded on the Double Diamond process model, and constitutes the procedure model of an evolving methodology. By capitalizing on the synergies between Design Thinking and Systems Thinking, this model offers a systematic and iterative framework to address the aforementioned challenge. The DT-MBSE integration model comprises three key entities, each fulfilling a specific role within the process. The first diamond focuses on identifying uncertainties, while the second diamond is dedicated to their mitigation. In the forthcoming application of the procedure model within the methodology, we perceive the interaction among the three entities as a challenge. We deem the transfer of data and information in the initial step of the model to be a fundamental challenge in model creation. Nevertheless, efforts are underway to address this challenge through the development of an ontology and an element library. An application and success validation of the process model will be conducted comprehensively as part of the methodology evaluation.

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