THE DESIGN OF A RESEARCH TOOL FOR CONDUCTING RESEARCH IN A COMPLEX SOCIO-TECHNICAL SYSTEM

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ABSTRACT

This article presents research relating to the challenges of conducting research in a complex socio-technical system. The result of this research is that a conventional research approach is fundamentally reactive, and does not always produce the desired results when applied to such a complex socio-technical system. The literature suggests that approaching the research from a problem investigation and problem improvement point of view will provide better results. This article describes the design of a research tool using a design science research methodology that can be used for such investigations and improvement identification and evaluation activities.

OPSOMMING

Hierdie artikel bespreek van die uitdagings wat ondervind word wanneer daar navorsing gedoen word in 'n komplekse sosio-tegniese stelsel. Die navorsing toon dat die tradisionele navorsings-benadering in 'n komplekse sosio-tegniese omgewing fundamenteel reaktief is, en dat dit nie altyd die gewense resultate teweeg bring nie. Uit die literatuur het dit duidelik geword dat 'n meer gewense oplossing is om die navorsing van uit 'n probleemondersoek- en probleemverbeteringsoogpunt te benader. Hierdie artikel bespreek die ontwerp van 'n navorsingsinstrument deur gebruik te maak van 'n ontwerpswetenskap navorsingsmetodologie. Dit kan gebruik word vir soortgelyke ondersoeke en vir die identifisering en evaluasie van moontlike verbeterings.

1 INTRODUCTION

Simon [1] postulated in his book, *The sciences of the artificial*, that we live in a world that contains both items that occur naturally and created artefacts. These artefacts can range from the buildings we live in and the vehicles we use for transportation through to the letter and number constructs we use to convey information. An artefact can be described as something that is created with a specific purpose, and that will only be of value if it provides the utility for which it was designed [1].

An artefact stands in contrast to a naturally occurring object such as the sun or a tree. Specific artefacts may be created to imitate items that occur in nature. Examples of these types of artefacts include products such as artificial diamonds or synthetic rubber. These items can be created using similar materials and processes as are found in nature, or from entirely different materials and using different methods. Irrespective of the process by which they are created, they are still expected to provide a specific utility or to exhibit desired properties to be of value. These desired properties or needs describe how the artefact ought to be and how it should function to achieve its goals [1].

The very nature of an artefact is such that the creation process, as well as the utilisation process, takes place in very close cooperation with the human or social element. This close interaction between the social aspect (the human) and the technology (the design, creation, and use of the artefact) results in a socio-technical system. Such a system is created when two jointly independent systems — the social and the technical — interact in a correlative way to produce a single outcome [2], [3], [4]. Within such a socio-technical system, the technical part is the result of the various processes, tasks, and technologies involved. The social part relates to the different attributes of the multiple stakeholders involved in the process, the relationship between these stakeholders, the reward system present within a particular society, organisation, or institution, and the reporting and authority structure that is present [2].

A socio-technical system can also be viewed as a practical system in which naturally occurring objects, as well as human-made objects, are present and in which practical problems arise. These practical problems can be seen as an unwanted or undesired state of affairs in which there is a gap between the current state and the desired state, as is perceived by the social element involved [5]. Many of these practical problems can also be considered to be wicked problems that can be difficult or near impossible to solve due to incomplete information, contradictory or changing requirements, and the complex interaction between the different elements present in the problem situation, resulting in a complex socio-technical system [5].

In general, the objective of research conducted in the natural, business, management, and social sciences paradigm is to explain and predict the behaviour of specific observed phenomena and to find new truths or proofs — as in, “Why do things work in the way that they do?” [6], [7], [8], [9]. This type of research is fundamentally reactive, as it tries to explain an event that has already occurred. Furthermore, it tends to follow the more conventional research approach of defining the problem, doing a literature review, stating a hypothesis, collecting data via some form of experimentation and analysis, documenting results, and coming to a conclusion [7], [10]. The goal of this type of research is to identify and codify emergent properties and to discover and formulate laws or theories that explain the observed organisational and human behaviour [10].

When approaching a research problem within a complex system, an intuitive approach for a researcher is to try to break the problem into smaller and more manageable parts. This method is referred to as a reductionist approach. While this approach may provide suitable results when performing research in the natural, business, or social sciences, it does not always yield the desired results when applied to complex socio-technical systems. One of the reasons identified for this failure is that complex or wicked systems, including complex socio-technical systems, contain many interconnected parts, with the resulting relationship between the interconnected parts being more significant than the individual parts themselves [11], [12].

A further problem facing a researcher working in a complex socio-technical system is that there is no single or unique way of defining complex or wicked problems, but many — depending on the viewpoint of the researcher. Therefore, there are also no clear criteria that can be used to determine when a problem has been solved or a specific research objective has been reached. Any added effort can only improve the situation. When attempting to solve or improve such complex or wicked problems by using traditional research processes, as was referred to previously, it is often found that these research approaches do not always yield the desired results [2], [5]. These shortcomings can be attributed to the sometimes-unpredictable interaction of the technical environment with the social nature of the problem domain, and the related inability to define and execute repeatable experiments.

An alternative approach is to view the stated research problem, first, as an investigation activity and, second, as an improvement activity. In both the investigation and the improvement activities, the first step is to establish a current baseline within a specific problem scenario, identify areas of improvement, make changes, and apply these improvements to the problem scenario. Once these improvement changes have been made, a new baseline can be determined that is compared with the original baseline to see whether any improvements have been realised.

This paper presents a design methodology for the design of a research tool that can be used in a complex socio-technical system using a design science research methodology. The research tool can be used to investigate the complex socio-technical system to determine a current performance baseline. Specific improvements can then be designed and evaluated on a simulation level. Only when the researcher feels comfortable that the solution could work within the simulated improvement can the improvement be implemented in the ‘live’ system or environment. This concept is shown in Figure 1.

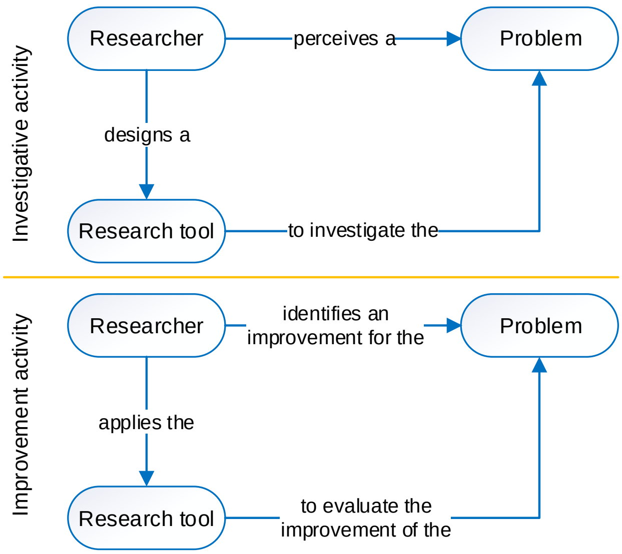

Figure 1: Application of design science research in addressing a complex socio-technical problem situation

This approach to problem-solving or problem-improving research using a design science research perspective will allow the focus of the research to shift from 'what was' to 'how something should be to provide a specific utility at some point in the future' by designing and applying an artefact to the problem context [10], [13], [14]. In contrast to the reactive nature of alternative traditional research methods, this approach is a more proactive approach.

1.1 Research methodology

The research presented in this paper is based on an inductive literature survey of the design science research paradigm and methodology. The results of the literature survey were then compared and combined with the relevant technical processes identified in the INCOSE *Systems engineering handbook* [15], using a deductive reasoning process with the focus on the design of a research instrument artefact.

1.2 Paper layout

The first section of the paper focuses on the design science research methodology. The sections that follow it present the specific implementation of the design methodology for the design of a research tool using a design science research approach. The last section provides a conclusion and recommendations.

2 DESIGN SCIENCE RESEARCH METHODOLOGY

This section provides an overview of design science as a research approach, a summary of some of the different views of design science research found in the literature, and an evaluation of the design science research topology.

2.1 Introduction

Design science, and design science research as a science, is concerned with the scientific study of design and the application of the design process in the systematic and scientific creation of knowledge about design and using design [16], [17], [18]. Aljafari and Khazanchi [19] described design science as the act of "exploring while building". Design science is a paradigmatic approach to research that is focused on solving a specifically identified problem. This type of research creates an artefact and positions it within the problem setting [16], [14]. In doing so, the researcher answers questions that are relevant to human problems, such that answers are obtained via the creation and use of innovative artefacts. These answers contribute new knowledge to the scientific body of knowledge. The artefact that is designed, and the process followed in designing and implementing the artefact, are fundamental to the understanding of the problem being solved [20].

Design science research aims to create new and innovative artefacts that can be used to address significant and essential problems, demonstrate the capabilities of the artefact, and predict the future benefits and risks of these artefacts [10], [21], [22], [23]. The roots of design science and design science research can be traced back to the work of Simon [1], who identified the concept of focusing research on the creation of artefacts from the viewpoint of "how things ought to be to attain goals, and to function" [1]. Wieringa [14] introduced the concept of the problem context as part of the definition of design science. In this definition, design science is defined as the design of artefacts and the investigation of these artefacts within the problem context for which they were explicitly designed. The objective of the artefact is to improve something within the problem context.

The artefacts constructed as part of the research process, as well as the problem context, can take several different forms, as shown below [8], [14]. **Error! Reference source not found.** Table 1 gives some examples.

Table 1: Examples of artefacts and problem context elements

Artefacts
• Software, hardware, components, and systems • Organisations • Constructs • Business processes • Methods • Techniques • Models
Problem context elements
• People • Values • Desires • Fear • Goals • Norms • Budgets • Software • Hardware • Conceptual structures

The most significant distinguishing factor between artefacts and context elements is that individual elements such as people, values, and fears, among others, cannot be designed, and thus cannot be artefacts [14].

Different design science artefacts have two common characteristics: (a) relevance, and (b) novelty [7]. These shared characteristics are used to distinguish design science research from conventional design, and to ensure that the artefacts are relevant to solving essential or current problems [7]. Hevner *et al*. [10] suggested that a design science research problem should either focus on unsolved problems that are unique, or find a better solution to an already solved problem. Design science should be distinguished from conventional design or 'best practices' types of design.

Another critical aspect to consider in design science research is that it is not the artefact itself that solves the problem, but rather the interaction between the artefact and the problem context. Applying the same artefact to a different problem context potentially yields a vastly different result [14]. The outcome of design science research can be evaluated in terms of new and improved theories and methods that find their way back to routine design activities and best practices design guidelines [10]. In practice, it is found that the types of problems solved via design science research tend to be more of a socio-technical nature [22].

2.2 Different views of a design science research methodology

Various researchers in the field of design science research, including Hevner *et al*. [10], [24], Peffers *et al*. [25], Wieringa [14], Iivari [26], and Venable, Pries-Heje and Baskerville [27] have published articles and books on the aspects that should be included in a design science research methodology.

Hevner [24] identified three cycles that form a core part of the design science research cycle: (a) the relevance cycle; (b) the design cycle; and (c) the rigour cycle (shown in Figure 2). In this model, the relevance cycle triggers the research process with an environment that not only identifies the requirements for the research, but also defines the acceptance criteria for the evaluation of the results of the research process. The output of the research process must then again be returned to the environment from which it originated to be studied and evaluated.

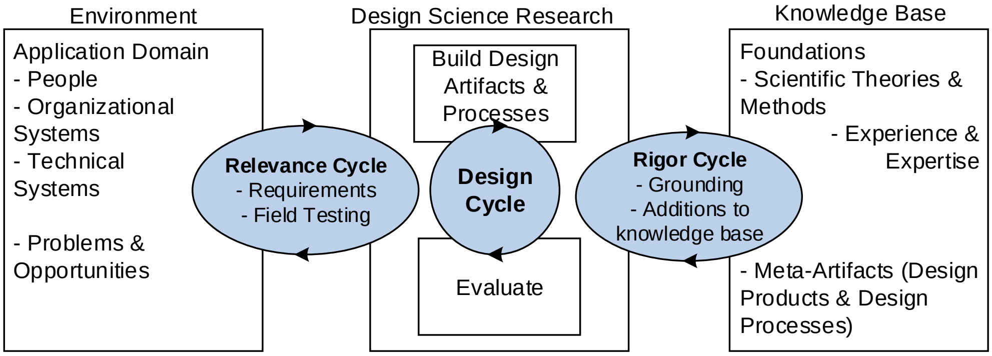

Figure 2: Design science research cycles (Redrawn from [24])

The design cycle is central to the design science research project. Within the design cycle, the research activity iterates between the design and realisation of an artefact, its evaluation, and the resulting feedback to refine the design [1], [24].

The purpose of the rigour cycle is to identify prior knowledge that is relevant to the research project to ensure its innovation. It is the researcher's responsibility to ensure that the designs produced are research contributions and not conventional designs based on the application of established processes [10]. The research rigour is dependent on the skill of the researcher in selecting and applying the appropriate theories and methods to constructing and evaluating the artefact [24].

Peffers *et al.* [25] included the following elements in their design science research methodology: (a) problem identification; (b) objectives of the solution; (c) design and development; (d) demonstration; (e) evaluation; and (f) communication.

Wieringa's [14] approach to a design science research methodology is to define a design cycle and an empirical research cycle. The design science research process iterates between these activities of designing an artefact to fulfil the desired utility or need, and the empirical investigation of this designed artefact within the problem context for which it was intended [14]. This design science research methodology approach is shown conceptually in Figure 3.

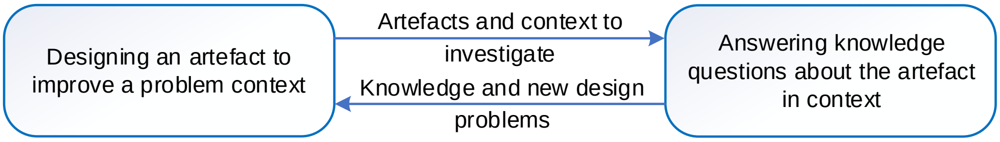

Figure 3: Design science research iterates between designing and answering knowledge questions (redrawn from [14])

This approach results in a two-cycle approach that splits the design science research methodology into two parts, functioning under the umbrella of the problem context. The first part is the design cycle, which is used as a logical problem-solving process. During its first iteration, this design cycle addresses the problem investigation, treatment design, treatment validation, and treatment implementation activities. Any subsequent iterations address the evaluation and improvement of the implementation. The second part of the research methodology is the empirical research cycle, which Wieringa defined as a rational way of answering scientific knowledge questions [14]. This methodology addresses the research problem analysis, research and inference design, validation, and research execution.

When comparing the various methodologies presented, three areas of commonality can be identified between the original three-cycle model proposed by Hevner *et al.* [10], and the subsequent work done by Peffers *et al.* [25] and Wieringa [14].
The first common area relates to the relevance of the research, which Hevner *et al.* [10] addressed with his relevance cycle. Peffers *et al.* [25] incorporated this concept in their "identify the problem and motivate" heading, which Wieringa [14] referred to as "the acquisition and validity of the objects-of-study" in his methodology.

The second common area relates to the research rigour cycle identified by Hevner *et al.* [10]. Wieringa [14] addressed this directly by specifying the use of empirical research methods.

The third common element is the design cycle identified by Hevner *et al.* [10]. Wieringa [14] addressed this with a design cycle that covers the main activities required to design an artefact. Peffers *et al.* [25] discussed the design activities as part of the topics of design, development, and evaluation.

Of the various design science research methodologies proposed, the methodology proposed by Wieringa [14] is the most comprehensive, except for the detailed activities and processes identified for the design cycle. An alternative approach to enhancing the design cycle was presented by Scribante, Pretorius and Benade [28], which expanded the design cycle proposed by Wieringa [14] to include elements of the technical process detailed in the INCOSE *Systems engineering handbook* [15].

2.3 Design science research topology

Research is not an activity that can be done in isolation, as the knowledge and insight gained from research must be shared with other researchers and stakeholders for it to contribute to the general body of knowledge. It is essential that the design of the investigative research tool artefact use recognised ontologies, boundaries, guidelines, and deliverables. This will ensure that the overall research design approach, and the communication of results, is understood primarily by other design science researchers, but also by other academic researchers in general [9], [24], [29]. To support the research process and to make the information sharable, Strang [9] defined a conceptual research model that addressed the research process as a four-layer, top-down topology. The four layers are the research ideology, the ontology, the research method, and the research technique. Aljafari and Khazanchi [19] expanded the research topology definition of Strang [9] by defining a new research ideology design/design science that stands at the same level as the positivist, pragmatist, and constructivist/interpretivist ideologies. Within this design/design science ideology, they provided descriptions for the ontology, epistemology, methodology, and axiology. The combined perspective is shown in Table 2.

Table 2: Philosophical assumptions for the design/design science research ideology [19], [30], [10]

Basic belief	*Design/Design science*
Epistemology	Knowing through making: objectively constrained construction within a context. Iterative circumspection reveals the meaning.
Ontology	Multiple, contextually situated alternative world states. Reality is socio-technically created and enabled.
Research strategy	Development; unit of analysis: an organisational or societal problem for deductive-inductive theory building.
Research method	Mixed methods; measure artefactual impacts on the composite system, action research, case study.
Research technique	Using a combination of surveys and single-case mechanism experiments in an action research setting.
The relationship between theory and practice	Design theory is used to build predictably functioning artefacts.

3 RESEARCH INSTRUMENT DESIGN PROCESS

This section addresses the research problem identification phase, the research problem definition phase, the research tool specification phase, the research tool implementation phase, and the research tool validation phase.

3.1 Research problem identification phase

This section will address the identification of the research problem and the definition of the research goals. The current knowledge will be established, as well as the research conceptual framework and the object of study. Finally, the identification of the alternative solution classes will be discussed.

3.1.1 Introduction

The research problem is identified by defining the research problem context in terms of a problem or opportunity that must be addressed, including the problem space within which the problem or opportunity resides, as well as the object-of-study. The following activities form part of the research problem identification phase.

3.1.2 Research problem identification

The identification and selection of the research problem that is to be studied using a design science research methodology can be evaluated against the criteria of (a) the relevance of the problem in terms of current or relevant difficulties; (b) the novelty of the problem in terms of its unique nature; and (c) the significance of the problem [22], [7], [10].

3.1.3 Research goals

The research goal is closely aligned with the identified research problem. The research goal is, in turn, divided into a design goal and a knowledge goal. In this article, the design goal is identified as the design and implementation of a research tool. This type of design goal can also be classified as an instrument design goal. Instrument design goals are achieved by solving design problems surrounding the design of the research tool. In turn, the knowledge goal is achieved by answering the posed knowledge questions by applying the research tool to the problem context [14]. The relationship between the instrument design goal and the knowledge goal is shown in Figure 4.

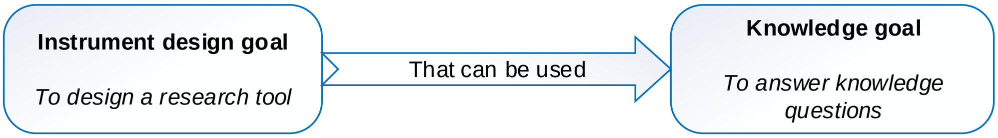

Figure 4: Relationship between knowledge goals and design goals (adapted from [14])

3.1.4 Current knowledge

The current available knowledge on the research problem or subject must be established. The function of the current knowledge is to serve as background support for the description of the observed phenomena, which helps to define the research problem. This knowledge can be obtained from a variety of sources, including professional literature such as published scientific, technical, and trade literature, or from subject matter experts (SMEs) in the field [15] [30] [14].

The search for and the description of the current knowledge provide a point of departure for the researcher. In some instances, it may turn out that, after the current available knowledge has been established, enough data already exists that either answers the knowledge goals or may reduce the scope of the study. Conventional research methods that the researcher can employ to establish the current knowledge include literature surveys and expert interviews. The current knowledge can be equated with the literature survey found in the traditional research methodology.

3.1.5 Research conceptual framework

The conceptual research framework provides the basis for reasoning why the research topic matters (is relevant) and why the research process is appropriate and rigorous. To support the arguments for relevance and rigour, the research conceptual framework should (a) map the research questions as an extension of the problem statement; (b) trace the research design through to the research goals, research questions, and context; (c) demonstrate that the data collected supports the analysis of the research questions; and (d) show that the selected inference and analytical process supports the answering of the research questions [31]. These items are summarised in Figure 5.

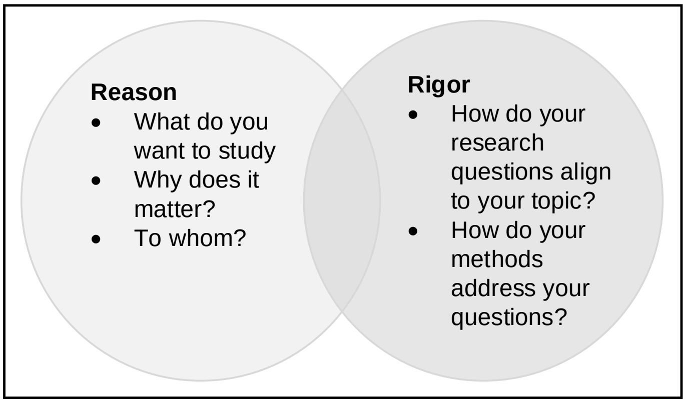

Figure 5: Relevance (reason) and rigour of the research process (redrawn from [31])

3.1.6 Object of study

The object-of-study in a design science research project is an artefact in context. It can be defined as the entity in which the observed phenomena occur from which measurements are to be made [14]. When designing a research tool — the focus of this article — the object-of-study changes. Instead of just studying the artefact interacting with the context, a research tool artefact must be designed that investigates a new problem context that now consists of the original problem artefact interacting with the original problem context [28].

The research tool artefact must thus be able to investigate the new problem context without influencing its operation. This will initially allow the researcher to observe the problem context and establish a performance baseline. This performance baseline can be re-evaluated based on specific changes that were made to the problem context (e.g., an improved process). The object of study for a research tool artefact is shown in Figure 6.

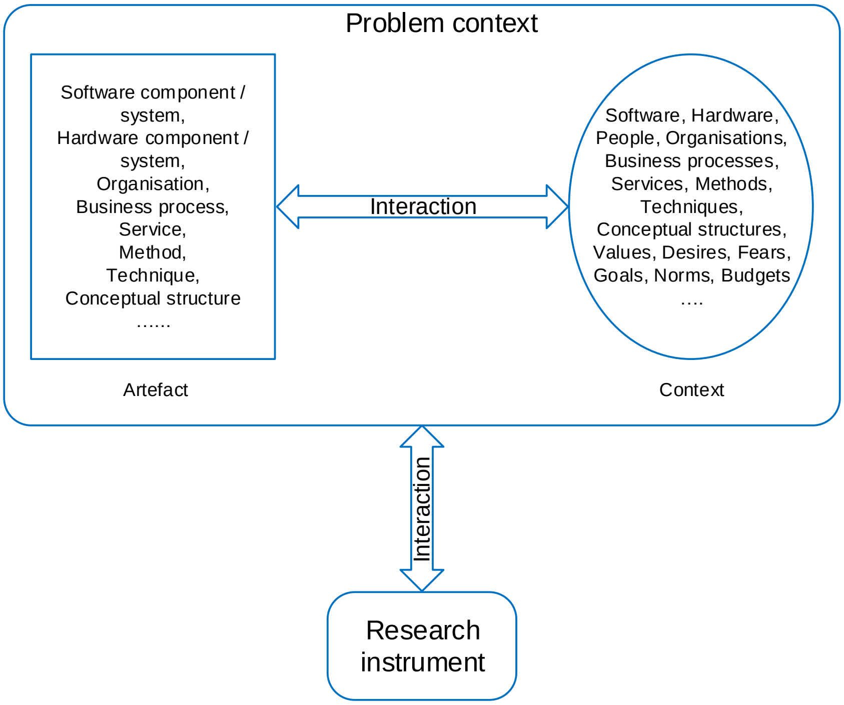

Figure 6: The object-of-study for the design of a research tool artefact [28]

The object-of-study is the part of the world with which the researcher interfaces in order to learn something based on a sample taken from the population of the problem context or a model of the population elements [14]. This is conceptually shown in Figure 7. Identifying the population and selecting the sample object-of-study to be studied depend on the nature of the research to be done. When doing case-based research, the aim is to study individual objects with the aim of generalising to similar objects. In sample-based research, the objective is to analyse samples with the aim of generalising to the whole population from which the samples were taken [14].

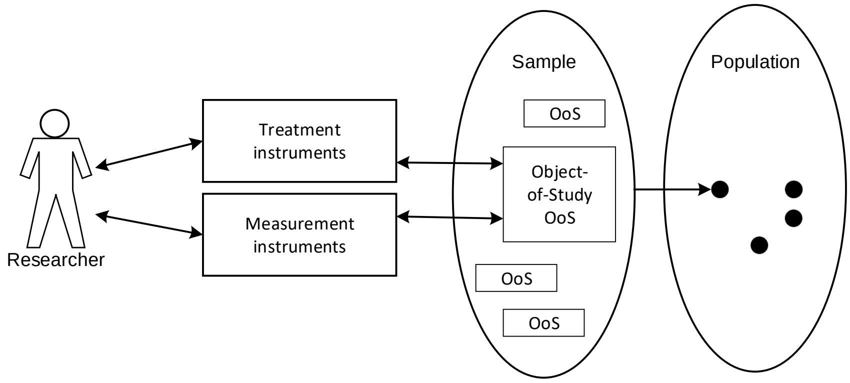

Figure 7: Relationship between the researcher, the object-of-study sample, and the population (redrawn from [14])

3.1.7 Identify alternative solution classes

There are normally alternative solutions that must be considered when designing the research tool artefact. These alternative solution classes need to be identified, and then the one that is best suited must be selected. The function of identifying the alternative solution classes and then making a selection is also a way to ensure that the researcher is not stuck in a rut by only using one tool, no matter what the problem is.

3.2 Research problem definition phase

Once the research problem has been identified, the research problem must be analysed in detail. During this process, the objectives of the solution are inferred rationally from the identified research problem. These objectives can be either quantitative or qualitative.

3.3 Research tool specification phase

Once the research problem has been defined in sufficient detail, the research tool specification must be established. The following aspects must be considered when drawing up the design specification:

1. Artefacts can constitute many different types of items, and include, among others, constructs, models, methods, instantiations algorithms, methods, notations, techniques, and even conceptual frameworks [10], [14]. The design activity includes determining the artefact’s desired functionality and architecture.
2. Different alternatives for artefacts should be considered and evaluated before selecting one or more alternative architectures or designs that meet the requirements.
3. The design of the specific implementation of the artefact should be consistent with the architectural entities as defined in models and views of the system architecture [15].

An essential aspect that must be considered when designing a research tool is that the research tool artefact must support the specific research and inference design. In doing so, the object-of-study, the sampling of the research population, and the measurements that will be performed must be defined. For the design of the inference process and method of the data collected, it must be decided whether descriptive inference, statistical inference, abductive inference, analogical inference, or a combination of these will be used to analyse the results [14].

3.4 Research tool implementation and verification phase

The purpose of the research tool implementation and verification phase is to define the architecture and the design of the artefact or research tool according to the previously established specifications.

Table 3: Aspects to consider when defining the research problem

Aspect	*Discussion*
Stakeholders identification	Establish who the stakeholders are, and define their goals, desires, and conflicts.
Observed phenomena	• What are the phenomena? • Why do they happen? (Causes, mechanisms, reasons.) • What are their effects if nothing is done about them?
Research conceptual framework	Identify the architectural and statistical structures [10], [23], [14].
Knowledge and research questions	• What are the observed phenomena? • What causes and effects can be identified? • What are the contributions of these phenomena to the stakeholder goals [14]?
Statistical structures	• What is the statistical population? • How are the population elements like or dissimilar to other elements?
Population	• Population predicate? • What is the architecture of the elements of the population? • What assumptions can be made regarding the chance models of the random variables?
Research operational concept	Establish research operational concept.
Identify correct requirements for the research tool	The following methods can be considered: • Systems thinking — hard systems thinking vs soft systems thinking — operation research, systems engineering, or situational awareness [32]. • Organisational cybernetics. • Complexity theory. • Soft systems methodology (approach or viewpoint). • Rich pictures (method). • Total systems intervention (these are all systems thinking methodologies). • Critical systems practice
Research tool requirements analysis	The identified requirements must be analysed to ensure that there are no conflicting, duplicated, or possibly missing requirements, and that the requirements form a coherent set [15], [14].
Research ethics	The research ethics must be established and included as part of the requirements set.

The research tool artefact can consist of one or more building blocks or elements that will be integrated to create the realised system (product or service) that satisfies the identified requirements, architecture, and design. The artefact realised at the end of this phase can range anywhere from being a software component, hardware component, business process, service, method, or technique, to a simulation model.

After the realisation and implementation of the research tool — but prior to its validation with actual research or field data — its essential operation must first be verified. The purpose of the verification process is to provide proof that a system or system element fulfils its specified requirements and characteristics [33], [15]. Activities such as inspection, testing, demonstration, and analysis can be used to verify the artefact. The primary purpose is to establish the effectiveness of the artefact in solving the problem by using experimentation, simulation, a case study, or other suitable activity, as indicated in Table 4.

3.5 Research validation phase

This validation can be done by performing several iterations of the intended research and data analysis cycles. Based on the results obtained, a conclusion can be drawn on how well the artefact will support the actual research process. This activity will involve comparing the objectives of the solution with the actual observed results from the use of the artefact in the demonstration. In order to achieve this, knowledge of the relevant metrics and analysis techniques identified as part of the inference design will be required [10].

Table 4: Design evaluation methods [10]

Evaluation method	*Specific implementation*
Observations	*Case study* — Study artefact in depth within the environment
	Field study — Monitor the use of the artefact in multiple instances
Analytical evaluation	*Statistical analysis* — Examine the structure of artefact for static qualities (e.g., complexity)
	Architecture analysis — Study fit of artefact in technical structure
	Dynamic analysis — Study artefact in use for dynamic qualities (e.g., performance)
Experimental	*Controlled experiment* — Study artefact in a controlled environment for qualities (e.g., usability)
	Simulation — Execute artefact with artificial data
Testing	*Functional (black box) testing* — Execute artefact interfaces to discover failures and identify defects
	Structural (white box) testing — Perform coverage testing of all execution paths in the artefact

The research data obtained during the solution validation process has to be checked for consistency to identify and correct data transformations and missing values, and to remove outliers [14]. Various questions can be asked during the solution validation phase. These questions can include the following [14]: (a) Did the selected cases have the architecture that was planned during research design? (b) Did any unexpected events occur during the study? (c) What happened during the analytical induction (i.e., sampling), and did it support the original design?

The generated results must be analysed and explained using causal, architectural, or rational reasoning methods. Furthermore, the general validity of the results must be examined to determine whether the methods used and the results obtained are transferable to similar cases or populations [14]. In the end, the obtained results should answer the knowledge questions posed during the research design process, and include a summary of the conclusions and the limitations of the findings [14].

The solution validation phase could also be used to evaluate the performance of different research tool artefacts when more than one artefact has been validated. The solution validation phase can also be used to assess the sensitivity of the research tool and to quantify the contribution of the research tool to the knowledge goals and improvement goals that were identified at the start of the study.

In the end, the purpose of the validation process is to evaluate the performance of the artefact in context, look at the trade-offs for the different types of artefacts when more than one has been validated, establish the sensitivity of the research tool, and quantify the contribution of the research tool to the knowledge goals and improvement goals identified at the start of the study.

3.6 Research communication or dissemination

The outcome of the overall research process is the knowledge that it contributes to the understanding of a phenomenon [23]. The results of the research process must be shared and communicated to the broader academic and technical community to be added to the general knowledge base and to ensure rigour in the research process. The research can be shared by communicating the problem and its importance, the artefact produced, its utility and novelty of design, and its effectiveness in answering the knowledge questions [10].

4 SUMMARY AND CONCLUSION

The point of departure for this article is that the world that we live in is an artificial world whose inhabitants are creators of artefacts. These artefacts will only be useful if they exhibit a particular utility that is required for a specific reason. The interaction between the social element in the form of the human, and the technical element in the form of the artefact, creates a complex socio-technical system.

Solving problems outright in such a complex socio-technical system is not always achievable. Some researchers even go so far as to postulate that it is not possible to find a solution that will solve the problem completely. The literature suggests that an approach to problem investigation to improve the problem situation should be followed instead. One of the possible research methodologies that can be applied to a complex socio-technical environment is that of a design science research methodology.

A design science research methodology is based upon the design and investigation of an artefact within its problem context. During the evaluation of the various design science research approaches proposed by different authors, it was observed that, while the empirical research effort is often discussed in detail, the design aspects of the artefact were glossed over. The structure of the research process proposed in this article includes an enhanced design cycle that incorporates tailored elements of the systems engineering process defined by INCOSE [15].

One of the central aspects of the design science research methodology is the concept of the object-of-study. This object of study consists not only of the artefact that is being designed, nor just of the problem context to which this artefact is being applied, but rather both the artefact and the problem context — and, most importantly, the interaction between the artefact and the problem context. In the case presented in this article, the objective was to design a research instrument. For this research instrument, a new object-of-study was defined such that the original artefact/problem context became the new problem context, and the research tool became the new artefact.

The newly defined research process includes the following phases:

1. Research problem identification
2. Research problem definition
3. Research tool specification
4. Research tool design, implementation, and verification
5. Research tool validation

The end-result of the design process is a research tool that is validated for use within its intended environment.

The main aim of the research presented in this article was to gain a better understanding of how to conduct research in a complex socio-technical system. During the research process, the researchers realised that no single 'silver bullet' solution can be found, but that the problem should instead be approached from an improvement point of view. In order to be able to do this, the researchers set out to design a research tool that could be used, first, to establish a current performance baseline in the organisation that is being investigated. The next step was to identify specific improvement actions, and, last, to define an environment that can be used to evaluate potential improvements prior to implementing these improvements in a real, live organisation. These objectives were met by developing a novel implementation of a design science research methodology with the aim of providing an improved and validated research tool.

The following main conclusions can be made from the research presented in this article:

1. Conducting research in a complex socio-technical domain is problematic, since describing the behaviour of the social element and generalising it are not always possible.
2. When conducting research in a socio-technical system with the aim of solving a problem, finding a complete and final solution may not always be feasible. In such a situation, it is better to aim for a problem improvement approach such that incremental improvements can be effected.
3. The use of a design science research methodology as the base research methodology for research in a complex socio-technical system can be argued to be a valid approach.
4. Enhancing the design cycle of the research design process by using the INCOSE systems engineering technical process as its basis added value to the overall design.
5. The use of a design science research methodology can add value in research areas other than just the academic environment; it could also be applied to real-life practical problems in the industry.

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