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Value-based Software Engineering: A Systematic Mapping Study

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Abstract

Background: Integrating value-oriented perspectives into the principles and practices of software engineering is fundamental to ensure that software development activities address key stakeholders' views and also balance short-and long-term goals. This is put forward in the discipline of value-based software engineering (VBSE)
Aim: This study aims to provide an overview of VBSE with respect to the research efforts that have been put into VBSE.
Method: We conducted a systematic mapping study to classify evidence on value definitions, studies' quality, VBSE principles and practices, research topics, methods, types, contribution facets, and publication venues.
Results: From 143 studies we found that the term "value" has not been clearly defined in many studies. VB Requirements Engineering and VB Planning and Control were the two principles mostly investigated, whereas VB Risk Management and VB People Management were the least researched. Most studies showed very good reporting and relevance quality, acceptable credibility, but poor in rigour. Main research topic was Software Requirements and case study research was the method used the most. The majority of studies contribute towards methods and processes, while very few studies have proposed metrics and tools.
Conclusion: We highlighted the research gaps and implications for research and practice to support VBSE.

Keywords: Systematic mapping, value-based software engineering, VBSE

1. Introduction

Value-based Software Engineering (VBSE) aims to incorporate value thinking into the wide range of Software Engineering principles and practices [1]. It opposes a value-neutral approach to SE practice and research, where value-neutral is described as [1]:

– "Every requirement, use case, object, and defect is treated as equally important";
– "Methods are presented and practiced as largely logical activities involving mappings and transformations (e.g., object-oriented development)";

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– "'Earned value' systems track project cost and schedule, not stakeholder or business value";
– "A 'separation of concerns' is practiced, in which the responsibility of software engineers was 'confined to turning software requirements into verified code', rather than to continuously maintain the consistency along the chain of evolving value propositions, system and software requirements, architecture and code."

Furthermore, one of main criticisms towards a value-neutral view is that it can also deteriorate projects' outcomes [1, 2]. A value perspective should be integrated into the full range of existing and emerging SE principles and practices, such as value-based requirements engineering, architecting, design and development, verification and validation, planning and control, risk management, quality management, and people management [1]. Finally, VBSE should be the basis for a framework in which the previously mentioned SE principles and practices "compatibly reinforce each other" [1, 2]. It is important to note that the context of "value" in this study refers to the broader definition of value as used in [2], that define value as "relative worth, utility, or importance" [2], in addition to the traditional and common definition of value, i.e., in terms of economics or monetary aspects [3].

After Boehm's seminal paper's publication, other VBSE publications followed, investigating value-based approaches and techniques in SE such as in [4–6]. It is important to know to what extent the proposed approaches and techniques contribute to software development or are used by practitioners, and whether the interest in value-based studies still persists or not. Therefore, the goal and main research contribution of this paper is to detail a mapping study aimed to identify primary studies in VBSE. The motivation to conduct this mapping study is to understand the research efforts that have been put into VBSE by providing a catalogue or classification of evidence of VBSE research. These include understanding the definition and context of value used in the studies, their quality and rigour, the VBSE principles and practices studied, the research topics and the publication venue. Our mapping study structures the VBSE body of knowledge through a systematic classification of evidence based on the VBSE definition and agenda given by Boehm (2003) [1].

This mapping study's key contributions are to: i) analyze how value is defined in VBSE studies and the quality of those studies, measured according to four categories (reporting, rigor, credibility, and relevance); ii) identify and summarize trends in the VBSE research (related to SE principles and practices) and the research gaps for future research; iii) identify and summarize the main topics researched in the studies, and the research gaps and topics for future interest, looking at publication trends over time; iv) reveal gaps for future research concerning the use of research methods, maturity of research based on the type of investigation, and possible opportunities for research and contribution types; and v) present the publication venue. We also document important research gaps to better inform both practice and future research in this field. The research questions for this mapping study and the motivations for each question are outlined in Table 1.

The remainder of this paper is organized as follows: Section 2 presents the background of research and the related work. Section 3 describes the research method. Section 4 presents the results from the mapping study followed by a discussion and threats to validity in Section 5. Finally, Section 6 concludes our work.

Table 1. Research questions and motivation

RQ#	Research Question	Motivation(s)
RQ 1	How value has been defined in the existing VBSE studies?	Understanding how value is defined is central to know how value can be used or has been practiced in any levels of decision-making in SE.
RQ 2	What do we know about the quality of VBSE studies, particularly on the quality of reporting, rigor, credibility and relevance?	To measure the quality of VBSE studies using a well-known classification proposed by [7]. Researchers can use such information to focus follow-up systematic reviews on studies of high quality.
RQ 3	What are the SE principles and practices investigated so far in VBSE, and how has this changed over time?	Researchers and practitioners can identify relevant practices in their areas of interest (e.g., requirements and VBSE) based on the catalogue/classification concerning SE principles and practices.
RQ 4	What are the most investigated research topics in VBSE, and how has this changed over time?	Researchers and practitioners can identify relevant papers for specific research topics based on the catalogue/classification concerning topics.
RQ 5	What are the research methods used in VBSE studies and how many studies looked at each method (e.g., case study, experiments, survey, etc.)?	To reveal gaps for future research concerning the use of research methods (e.g., showing the needs for more industrial studies – e.g., case studies) in VBSE areas.
RQ 6	What are the research types that these studies apply (e.g., validation/evaluation/solution proposal, etc.) and how many studies looked at each research type?	To reveal gaps for future research concerning the types of research documented.
RQ 7	What contribution facets do they provide (e.g., process, method, model)?	To reveal gaps for future research concerning the contribution facets, (e.g., showing which contribution facet is lacking).
RQ 8	What are the publication venues for VBSE research?	To provide awareness about where VBSE papers have been published.

2. Background and related work

2.1. Concepts of VBSE

The value-based paradigm in SE has emerged when several authors promoted "value" as a basis for decision-making in software engineering rather than relying on "cost" alone (e.g., [8]. One of the arguments is that "value-neutral "approaches in software development are unable to deal with most of the sources of software project failure [9]. Under the "value-neutral" setting, the focus is more on the technical aspects such as quality, cost, and development time, and where decisions made about a software project are "de-coupled from the value propositions that established the project" [1]. Conversely, under a "value" setting, all participating stakeholders (e.g., customers, developers, managers, finance, marketing) must understand and handle each other's value propositions. Therefore, the goal is to create a product or service that adds value to all the stakeholders [1]. Hence, VBSE aims to bring value considerations more prominent so that software engineering decisions at all levels can be optimized to meet the objectives of the stakeholders [2].

Boehm [9] defined VBSE as "the explicit concern with value concerns in the application of science and mathematics by which the properties of computer software are made useful to people". The application of science includes both social and physical sciences, whereas

the mathematics perspectives include the utility theory, game theory, statistical decision theory, real options theory as well as logic, complexity theory, and category theory [9]. Since software is expected to be "made useful to people", the inclusion of economics, management science, cognitive sciences, and humanity are required to create a successful software system [2]. As such, VBSE is emphasized as "a multifaceted, multidisciplinary approach that covers all practices, activities, and phases involved in software development, addressing a wide variety of decisions about technical issues, business models, software development processes, software products and services, and related management practices." [2].

To address such multifaceted and multidisciplinary aspects of VBSE, an initial "4 + 1" theory of VBSE has been developed by Boehm and Jain [10]. The core of the theory is the stakeholder win-win Theory W (also known as the Enterprise Success Theorem), which states, "Your enterprise will succeed if and only if it makes winners of your success-critical stakeholders" [10]. The theory provides a process framework for guiding VBSE activities, addressing two major questions: "which values are important?" and "how is success measured?". The theory is supported by four other theories known as utility theory, decision theory, dependency theory, and control theory [10].

2.2. VBSE principles and practices

The aim of VBSE as a discipline is to integrate value-oriented perspective into all of the software engineering aspects such as requirements engineering, architecting, design and development, verification and validation, planning and control, risk management, quality management, and people management [1]. Hence, we used as basis the existing and emerging SE principles and practices outlined in the VBSE agenda [1] as follows:

- **Value-based requirements engineering:** Principles and practices to identify a system's success-critical stakeholders and to elicit and reconcile value propositions with respect to the system.
- **Value-based architecting:** Reconciliation of the system objectives with achievable architectural solutions.
- **Value-based design and development:** Techniques to ensure that software design and development process incorporates value considerations.
- **Value-based verification and validation (V&V):** Techniques to ensure a software solution satisfies its value objectives and provide ways to prioritize V&V tasks.
- **Value-based planning and control:** Incorporates the value delivered to stakeholders in terms of cost, schedule and product planning and control techniques.
- **Value-based risk management:** Incorporates value in identifying, analyzing, prioritizing and mitigating risk.
- **Value-based quality management:** Prioritizes desired quality factors that relate to stakeholders' value propositions.
- **Value-based people management:** Build stakeholder's team, manages expectation, reconciles stakeholder's value propositions, and integrates ethical considerations in a project's execution.
- **Theory of VBSE:** Application and development of theories in VBSE.

2.3. Related literature reviews

One of the earlier publications on VBSE was published as an edited book [2]. This book consists of fully refereed chapters providing foundations of VBSE, and mainly focusing

on software engineering decisions and their consequences from a value-based perspective. These include a presentation of state-of-the-art methods and techniques for evaluation of software products, services, processes and projects from an economic point of view. Additionally, the benefits of VBSE are also demonstrated through examples and case studies. This book, however, cannot be considered as a secondary study of VBSE research, but simply a compilation of chapters relating to a wide range of VBSE topics.

With regard to secondary studies, the first fully refereed publication we are aware of is by Khurum et al. [11] who performed a mapping study that relates to value but which sole focus was to identify value propositions or factors that have been used and should be considered while making decisions about software product development and management relating to software intensive products. They also included primary studies outside VBSE domain that were published in fields such as economics and marketing. The results from their mapping study were used to build a classification of value propositions called the Software Value Map (SVM). Their mapping study covered a period from 1969 to 2010, and has no overlap with ours. While our mapping study aims to provide a detailed overview of the VBSE domain, their study focused solely on identifying value propositions to be used to build the SVM classification.

The second fully-refereed secondary study we are aware of is Khan and Khan [12]. They presented a literature review focusing upon the impact that the adoption of a "value-based" approach to SE had upon software reusability and quality. Their analysis, limited to only ten (10) studies, presents different value-based pricing criteria, selection of automated tools, existing Component off the shelf (COTS), and conflict resolutions among different stakeholder value propositions. They reference Barry Boehm's work; however, some of the primary studies included in the paper are not "value-driven"; rather, they see value solely as financial, monetary value. This study also does not provide an overview of the VBSE domain, and, like [11], includes studies that are outside the VBSE domain.

The third study relating to this work is a much shorter version of this mapping study [13], which is a paper we published in 2019, covering three of the eight RQs described herein. The differences between what was reported in [13] and what is reported herein are as follows:

- The study in [13] presented results for the RQs 3 to 5, covering the period 2003 to 2017, and without investigating the change in trends over time. Herein we also present the results for RQs 3 to 5, however covering a wider period (2003 to 2020), and also investigating whether trends have changed over time (RQs 3 and 4).
- Herein we have also extended the number of RQs to 8, and covering a range of different aspects relating to VBSE research (e.g., value definition, studies quality, research types used, and contribution facets employed). We also include publication venues of VBSE research.

Finally, there is also a grey literature Masters thesis [14] that provides a mapping study of value in SE, by means of 364 studies published within the timeframe between 1990 and 2010. Although their study aimed to classify the contributions of VBSE studies and investigated the practical application and validation of the solutions in industry, quite a number of their included studies are non-VBSE studies. Further, the overall mapping focused on the software development process areas, the research types and contributions of the study. In our mapping study, we included data covering the VBSE agenda, value definition, the research quality, methods and publication venue of VBSE studies in addition to the contributions facets and the research types.

In summary, we believe that the additional set of RQs, and the extensions to the three RQs detailed in [13], provide a significant additional research contribution, when compared to what was documented in our previous work [13]. Furthermore, given that to date there is no fully-refereed and/or rigorously conducted mapping study that provides a detailed overview of VBSE, we see this as an additional and significant contribution of this work.

3. Research method

In conducting this mapping study, we refer to the guidelines presented in [15] and [16]. The activities involved are illustrated in Figure 1, which consist of three phases: planning, executing and reporting. Beside each activity, there is also the identification of each of the author(s) – 1 for first author, 2 to second author and so forth, who participated in that activity.

The planning phase relates to making decisions such as identifying the mapping study's goals, defining the scopes, research questions, search strategy, selection criteria, and defining

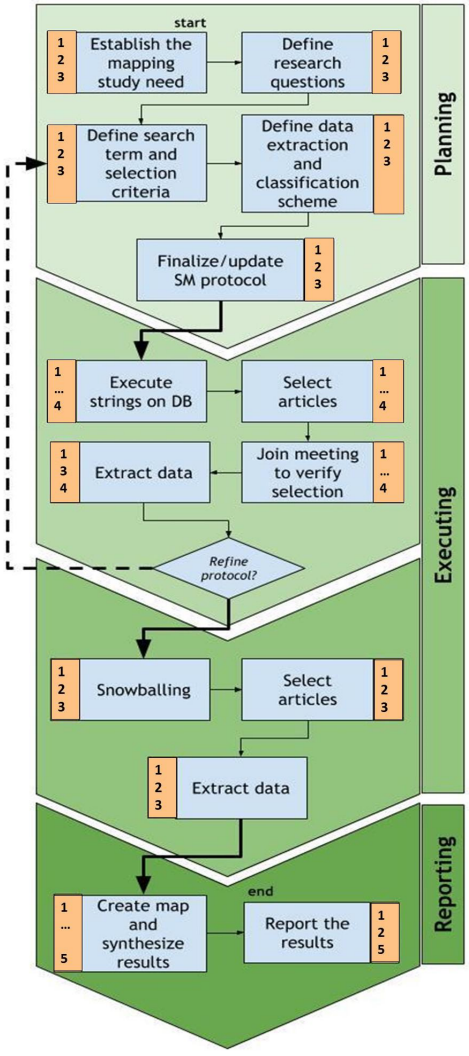

Figure 1. Systematic mapping process

the data extraction and classification process. In the second phase (Executing), the tasks include all the processes that relate to the mapping study's execution, which include study selection, and data extraction. All the first four authors have been involved in the selection of articles, and numerous joint meetings were held to verify study selection. The search results retrieved from online databases were entered to Parsifal (web-based tool). Once we finalized the list of included studies, a backward snowballing search was conducted. For validation of data extraction, we identified the disagreements in the extracted data and resolved through a joint meeting. The last phase – Reporting, represents the reporting and the results evaluation. The first, second, third and fifth authors were involved in this phase to synthesize and write-up the results. We carried out checks and balances through joint meetings held between the authors. We refer to the SEGRESS Guidelines [17] for reporting this mapping study. Our replication package is also available at the following link: https://zenodo.org/record/7901667#.ZF84uexByu5

3.1. Search strategy

Since our mapping study aims to search for relevant studies reporting value-based Software Engineering research, we used the following string:

```
((``value-based'' AND ``software engineering'') OR (``value-based software
    engineering'') OR (``value based'' AND ``software engineering'') OR
   (``Value based software engineering'') OR VBSE) OR ((value OR ``value
 based'' OR ``valuation'' OR ``value creation'') AND (``economics based''
     OR ``decision making'' OR economics OR ``software project'') AND
    (``software engineering'' OR software OR ``software development''))
```

The string was created based upon the following strategy:

1. **Keyword:** "value-based software engineering"
   Synonyms/adaptations: "value-based" AND "software engineering"; "value based" AND "software engineering"; "Value based software engineering"; VBSE.
2. **Keyword:** "value"
   Synonyms/adaptations: "value based"; "valuation"; "value creation".
3. **Keyword:** "software engineering"
   Synonyms/adaptations: "software"; "software development".
4. **Sub-string:** ("economics based" OR "decision making" OR economics OR "software project").

The choice of these terms is due to the fact that in the early days software companies are forced to create value along many dimensions mainly on the economic, social, cognitive, etc. [2]. Software developers also need to know the economic implications of their decisions in development process, hence analyzing economic value is considered a complex task. The terms "economics based", or "economics", as well as "decision making" in "software project" are commonly appeared in the VBSE literature that we were aware of. We have conducted an automatic search on electronic databases, which was later complemented with snowballing [18]. In relation to the electronic search, we selected articles published up until September 2020.

3.2. Databases

We included online databases that indexed each of the VBSE papers already known prior to conducting the study. In addition, there were also previous systematic literature reviews

and mapping studies that provide recommendations on the most adequate online databases to use (e.g., [19]). Based upon both, we decided to use the following databases: IEEEXplore, ACM digital library, Scopus, ScienceDirect, ISI Web of Science, and SpringerLink. These databases were selected because they have been considered as relevant ones by Dyba et al. [20] and Kitchenham and Brereton [21]. Note that although there are a few other potential databases such as EI compendex, Wiley Interscience (Wiley Online), Inspec and Kluwer as identified in [22], these databases were excluded in our mapping study due to the high degree of overlap among the databases, as reported by [19].

3.3. Study selection

Based on the guidelines presented in [15] and [23], we used the selection criteria as shown in Table 2. The main inclusion criteria were to consider any VBSE related studies, and for VBSE to be mentioned either in the title, abstract or keywords. This means that only studies that considered value aspects as per the value-based principles defined by [1] were considered. However, despite the use of a validated search string, and more strict inclusion criterion (IC 02), the study selection phase was not straightforward because in many cases we were unable to decide on whether to include or exclude a paper based solely on the paper's title, abstract, and keywords. In most cases their full text had also to be referred to, so to be sure that the paper presented a VBSE research.

Table 2. Inclusion and exclusion criteria

Inclusion criteria
IC 01 – Studies that are related to VBSE IC 02 – The title and/or abstract and/or keywords do(es) explicitly mention(s) VBSE IC 03 – Fully refereed journal and conference papers, and book chapters IC 04 – Articles/chapters written in English
Exclusion criteria
EC 01 – The publication lies outside the SE domain EC 02 – The publication is a grey literature (e.g., thesis) EC 03 – Papers not written in English EC 04 – The full text of the paper is not available EC 05 – The publication is within the SE domain but not related to VBSE

3.4. Classification scheme

To create a map of VBSE publications, we applied the general classification approach suggested by [23]. General classification refers to classifications that are used by majority of mapping studies [23]. In this mapping study, we referred to the following classifications: i) research topics, ii) publication venue, iii) research method, iv) research type, and v) contribution facet.

3.5. Data extraction

The items used for the data extraction are shown in Table 3, where we can also see which extracted data was used to help answer the RQs. The data extracted from each paper are

stored in a Google spreadsheet using the items listed in Table 3. The strategies used in extracting the data are described below:

- **Value definition:** The term "value" is searched throughout the paper to identify if there is any specific definition given, and whether the authors refer to Boehm's seminar paper [1] or VBSE book edited by [2] in determining the context of value or value-based used in the study.
- **Quality of study:** The quality of studies is rated quantitatively based on four aspects: reporting, rigor, credibility, and relevance, based on the classification of research quality proposed by [7].
- **VBSE principles and practices:** Classification of VBSE principles and practices is determined based on the agenda in [1] (e.g., VB requirements engineering, VB planning and control, etc.). We searched for specific agenda reported in the paper, however if it is not explicitly mentioned in the title, abstract or introduction Section, we inferred based on the objective(s), aim(s) and the outcomes of the study.
- **Research topic:** Articles were classified according to the SWEBOK's Knowledge Areas [24], identified based upon their keywords, main topic and focus. Major keywords (e.g., keywords and terms appeared in the title) and the dominant focus of each study are captured to identify the topics investigated. This is performed through a qualitative analysis of each primary study. The identified keywords and topics were then classified or grouped using a broader category and then we mapped these categories to the Knowledge Areas defined in SWEBOK [24] (e.g., [S99] focuses on requirements negotiation, hence classified under the Requirements Knowledge Area). The same method has been applied in [25] using the earlier version of SWEBOK.
- **Research method:** Research method is classified based on the methodologies suggested in [26, 27]. These include: Controlled Experiment, case study, survey research, ethnography, action research, simulation, prototyping, mathematical analysis, mathematical proof properties, literature review, and mixed method.
- **Research type:** Research type is identified based on the category defined in [27] and using the decision table for research type classification suggested in [23].

Table 3. Items for data extraction

Data item	RQ
Study ID	–
Value definition	RQ1
Quality of study (reporting, rigor, credibility, and relevance)	RQ2
VBSE principles and practices (according to VBSE agenda [1]), e.g., VBRE, architecting, designing and development, etc.	RQ3
Research topic (e.g., software requirements, software design, etc.)	RQ4
Research method (Controlled Experiment, case study, survey research, ethnography, action research, simulation, prototyping, mathematical analysis, mathematical proof properties, literature review, mixed methods)	RQ5
Research type (e.g., evaluation/validation/solution proposal/philosophical paper/experience report/opinion paper)	RQ6
Contribution facets (i.e., type of intervention, e.g., process, method, model, tool, or metric)	RQ7
Publication venue (e.g., conference, journal, etc.)	RQ8
Bibliographic information (title, abstract, publication year, country)	Demographics
Study context (i.e., context being studied, e.g., academic, industrial, government, organization context, etc.)	Demographics

- **Contribution facets:** Contribution facets are identified based on the type of contributions as suggested in [23], which classify contributions as a process, method, model, tool or metric. We used as basis the term mentioned in the paper when extracting the contribution facets.
- **Publication venue:** We considered peer-reviewed venues, which include journals, conferences, and workshops as per [23].
- **Study Context:** We employed the study context as per [23]. This includes academic, industrial, government, and organization context.
- **Trends of research:** This is measured by counting the number of publications per year for each VBSE agenda item proposed by [1].

4. Results

4.1. Overview

Our mapping study's search and study selection process comprised three (3) stages, as shown in Figure 2. During Stage 1, we conducted electronic searches on six (6) online databases and retrieved a total of 6536 studies. The results of our automated search process are summarized in Table 4. Results showed most of the included papers were from Scopus (54), followed by IEEEXplore (28), and ISI Web of Science (27).

In Stage 2, we selected relevant studies based on the inclusion and exclusion criteria. Out of 6536 studies, we selected 126 studies that fulfilled the criteria. In Stage 3, we conducted a backward snowballing, using the included studies as seed set, in order to manually check paper references for possible inclusion of other relevant studies. Out of 3273 references, we selected 17 studies that fulfilled our selection criteria. Hence, the final count of selected studies was 143 studies, 126 from the screened automated searches, and 17 from

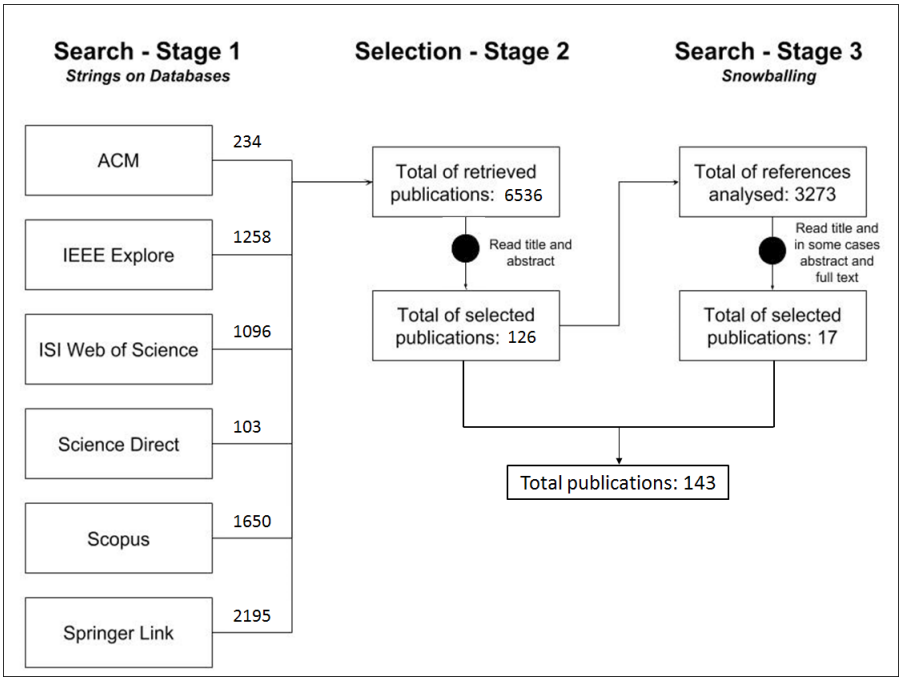

Figure 2. Study selection process

reference snowballing. These 143 studies are listed in Appendix A. Each study is identified as Sn, where n represents the study's number. Out of these 143 studies, 37 (26%) were published in journals, 88 (61%) in conference proceedings and the remaining 18 (13%) as book chapters. Figure 3 shows the number of studies that were published each year, since 2003. During the first two years (2003 and 2004) there were only five and two studies published, respectively; publication numbers peaked in 2006 with 24 studies (12 of these were book chapters in the VBSE book [2]). Overall, we have seven years (2005, 2006, 2007, 2008, 2009, 2010 and 2013) with at least 10 publications per year, followed by another six years (2003, 2011, 2012, 2014, 2015, 2017) with at least 5 publications per year. Since 2017 numbers have declined, with only two publications in 2019 and one publication in 2020.

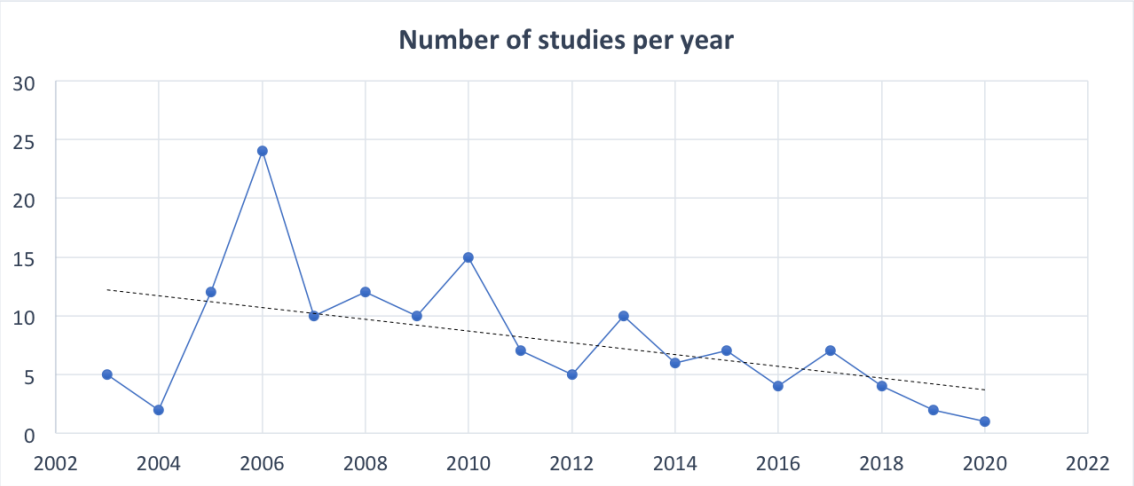

Figure 3. Line plot for the number of publications per year

4.2. Value definitions (Research question 1)

How value has been defined in the existing VBSE studies?

One important element in studying VBSE literature is to explore and to understand the notion of "value" in the primary studies. In particular, it would be interesting to know how did the studies define value, or the aspects of value the researchers are concerned with, and whether or not the notion of value goes beyond the conventional concepts of value, i.e., in terms of monetary or financial aspects. Analysis of value concepts can provide insights to

Table 4. Search results

Database	Retrieved	After removing duplicates	Excluded	Included
ACM	582	234	223	11
IEEE Xplore	1936	1258	1230	28
ISI Web of Science	1590	1096	1069	27
Science Direct	800	103	101	2
Scopus	2825	1650	1596	54
SpringerLink	2910	2195	2191	4
TOTAL	10643	6536	6410	126

the practitioners and researchers on the definition of value, including the measures used for assessing value.

In extracting the value definition used in the primary studies, we searched the term "value" throughout the paper and also identify the reference(s) related to VBSE cited in the paper, e.g., Boehm's seminal paper [1], VBSE book edited by [2]. The "value" term was first searched in the abstract, Introduction, and Conclusion, to determine if the "value" or "value-based" concepts are defined explicitly in the paper. The checking continued to the remaining Sections when no definite definition on value or value-based is found in the above mentioned Sections.

While there is no standard or commonly accepted definition of the term "value" used in the primary studies, we found that majority of the studies (85%, 122 out of 143) refer to either VBSE as defined in [1] or generally cite the VBSE book [2] when describing the context of value-based in their studies. Nonetheless, there are 15 studies (10%) that provide a clear definition of the term "value" applied in their studies (see Appendix B). In the context of VBSE studies included in this mapping study, most studies treat value as beyond the monetary or financial value. For example, value is defined as "relative worth, utility, or importance" [S9], [S20], [S49], [S143], "customer loyalty, innovation technology, cost reduction" [S25], "degree of desirability" [S77], "benefits derived from the product" [S101], "requirements fulfillment" [S110].

Although many researchers focused on the multi-dimensional perspectives of value, the economic perspective of value is undeniably important. This is because economics are considered most important in making business decisions, and as such form the basis of valuation of software assets and projects [S47]. According to Erdogmus et al. [S47], the process of determining the economic value of a product or service is not straightforward due to uncertainty in software development project. Several techniques such as decision-tree and real-options theory can be used to demonstrate how valuation can help with dynamic decision making under uncertainty. Earlier proponents such as in [8] have also promoted the concepts of economics or business value in support to decision making in software engineering.

One notable definition of value that is not related to economics, utility or functional value is given by Thew and Sutcliffe [S139]. Values in their study are defined as "personal attitudes or long-term beliefs, which may influence stakeholder functional and non-functional requirements". Values are also interpreted as "a set of issues which are frequently referred to as problematic in the RE process, such as politics, culture, sensitivities about the consequences of automation and conflicts between stakeholders" (p. 443). They mentioned that 'socio-political' issues such as emotions, values and people's feelings are often cited as problems in Requirements Engineering, hence proposed a method for analyzing such issues. They proposed a VBRE method that guides the elicitation of stakeholders' values, motivations, and emotions. Similar to [S139], we found another study [S15] that also considered value as personal beliefs and attitudes. In [S15], they referred to Schwartz's Value Theory [28], which emphasizes the profound nature of value in combination with an analysis of human motivation. The basic values are classified as: Power (authority/wealth), Universalism (equality/justice), Achievement (success/ambition), Benevolence (helpfulness), Hedonism (pleasure), Tradition (humility/ devotion), Stimulation (exciting life), Conformity (obedience), Self-determination (creativity/freedom), and Security (social order). In addition to these basic values, [S15] also referred to Holbrooks Typology of Consumer Value that defines consumer value as ''an interactive, relativistic preference experience''. Based on the

concepts of basic values and consumer values, the authors in [S15] proposed a meta-model to capture consumer preferences to be accommodated in IT system development.

Although the majority of studies applied the value-based concept as described in [1], or referred to the VBSE book [2] in general, we found 21 studies that have neither cited [1] nor [2] with regard to the "value" concept used in their studies (see Table 5). For example, in [S12], value is referred as business goals (cost, time to market, etc.) and the Return-on-Investment (ROI) technique is used to measure the business value. A total of 48 studies (see Table 5) refer to the stakeholder's value or perceived value from multiple stakeholders. Studies that focused on stakeholders' value propositions are mainly concerned about prioritizing requirements based on each requirement's perceived value, e.g., [S8], [S13], [S32]. Finally, there are 14 studies that focus on customer value or value creation in Agile (e.g., [S10], [S33]).

Table 5. List of studies – value perspectives

Value perspectives	Studies	# Studies
Studies that provide explicit definition of value	[S9], [S15], [S20], [S25], [S26], [S38], [S47], [S49], [S77], [S95], [S101], [S110], [S126], [S139], [S143]	15 studies
Studies that used value-based concept based on either Boehm's definition of VBSE [1] or VBSE book [2]	Majority of the studies (85%)	122 studies
Studies that neither cite [1] nor [2]	[S12], [S15], [S27], [S62], [S82], [S113], [S114], [S119], [S123], [S124], [S125], [S127], [S128], [S132], [S133], [S134], [S135], [S136], [S138], [S139], [S142]	21 studies
Studies that refers to or focus on stakeholder's value or perceived value	[S8], [S13], [S16], [S20], [S21], [S24], [S28], [S29], [S32], [S34], [S37], [S38], [S41], [S43], [S44], [S45], [S48], [S51], [S52], [S53], [S55], [S57], [S60], [S63], [S65], [S67], [S69], [S70], [S72], [S75], [S81], [S86], [S91], [S97], [S99], [S102], [S103], [S104], [S105], [S107], [S108], [S111], [S112], [S116], [S117], [S125], [S135], [S140]	48 studies
Studies that focus on customer/consumer value or creation of business value in Agile	[S10], [S33], [S56], [S61], [S62], [S64], [S82], [S84], [S88], [S89], [S115], [S119], [S127], [S136]	14 studies

Summary of key findings:
1. The term "value" or the concept of "value-based" has not been clearly or explicitly defined in many VBSE studies but most studies have cited either the seminal paper by Boehm [1] or the VBSE edited book [2].
2. Most of the studies defined "value" from the perspective of relative worth, or utility, as compared with economic value.
3. The measures used to evaluate or represent value is not explicitly mentioned neither described in many VBSE studies.

4. The varying notions of value concepts could potentially hinder the development of software systems, hence require collaboration with practitioners in order to implement specified values in software development.

4.3. Quality assessment (Research question 2)

What do we know about the quality of VBSE studies, particularly on the quality of reporting, rigor, credibility and relevance?

To address this research question we have used a classification of research quality proposed by [7], where the quality of primary studies is assessed based upon 11 criteria, arranged into four main aspects. This is a detailed quality criteria that does not have the high level of ambiguity of other existing proposals in Software Engineering [29]. This classification's four main aspects and the corresponding criteria are as follows:

1. Reporting – Contains three criteria that assess the quality of reporting of a study's rationale, aims and context. The three criteria are:
   a) Is the paper based on research (or is it merely a "lessons learned" report based on expert opinion)?
   b) Is there a clear statement of the aims of the research?
   c) Is there an adequate description of the context in which the research was carried out?
2. Rigor – Contains five criteria that assess the thoroughness of the "research methods employed to establish the validity of data collection tool and the analysis methods". It characterises the "trustworthiness of the findings". The five criteria are:
   a) Was the research design appropriate to address the aims of the research?
   b) Was the recruitment strategy appropriate to the aims of the research?
   c) Was there a control group with which to compare treatments?
   d) Was the data collected in a way that addressed the research issue?
   e) Was the data analysis sufficiently rigorous?
3. Credibility – Contains two criteria that assess the trustworthiness of the study's methods so to ensure that "the findings were valid and meaningful". The two criteria are:
   a) Has the relationship between researcher and participants been adequately considered?
   b) Is there a clear statement of findings?
4. Relevance – Contains one criterion that assesses the importance of "the study for the software industry at large and for the research sommunity". The criteria is: Is the study of value for research or practice?

Each of the 11 criteria was measured as "yes" or "no", and later we counted the number of "yes" for each of the four main aspects, for each of the 143 studies. This means that the range of values for each main aspect was as follows: Reporting (0–3); Rigor (0–5); Credibility (0–2); and Relevance (0–1). We have also associated labels with these values, which are used below while discussing the results, and also in the Discussion Section, when comparing quality to other aspects also investigated herein. The labels used are as follows:

- Reporting: 0 – Unsatisfactory; 1 – Acceptable; 2 – Good; 3 – Very Good.
- Rigour: 0 – Unsatisfactory; 1 – Poor; 2 – Acceptable; 3 – Good; 4 – Very Good; 5 – Excellent
- Credibility: 0 – Unsatisfactory; 1 – Acceptable; 2 – Good; 3 – Very Good.
- Relevance: 0 – Unsatisfactory; 1 – Very Good.

The 11 criteria for each of the 143 papers are measured, and the summary results are shown in Figure 4. It shows that the majority of studies presented very good reporting quality and relevance. The results for studies' rigour were somewhat mixed, with the largest number of studies showing poor rigour, followed by very good and unsatisfactory rigour. As for credibility, the majority of studies presented acceptable credibility, followed by good credibility. Two quality aspects – relevance and reporting, provided results showing that a clear majority of studies were judged to be very good. However, rigor and credibility do not present the majority of studies with higher quality. In fact, most studies were judged to present acceptable credibility only, and poor credibility.

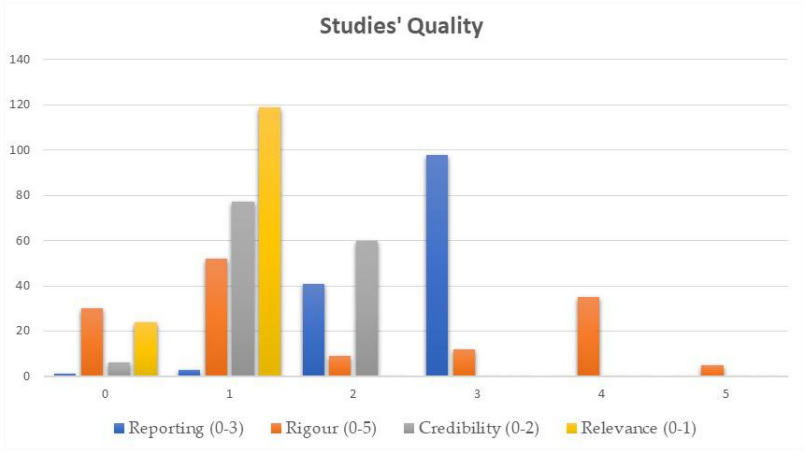

Figure 4. Studies' quality as per four main quality aspects

The 11 quality criteria used to assess the studies' quality is shown in Figure 5. It shows that out of the five criteria used to assess rigor, only criterion 7 presents a "Yes" for most studies. The worst result was for criterion 6, which represents an important aspect to manage when carrying out formal experiments. Furthermore, criterion 8 – data analysis used, also seemed to lack rigor for a large number of studies (102), and criterion 5 also showed that many studies (91) lacked the use of an appropriate recruitment strategy. Such poor results, particularly for criteria 5, 6 and 8, were also observed by [7], when assessing 33 empirical studies of agile software development. Their best results were also obtained for Reporting and Relevance. However, unlike the studies investigated by [7], the ones included in this mapping study were characterised by a large number of studies that did not carry out empirical investigations. Instead, they provided detailed examples – proof of concept, about the solutions they were proposing (e.g., prioritization technique, tool). A total of 44 studies (31%) were proof of concept studies. Another set of 20 studies (14%) presented proposals without a detailed example and no empirical evaluation or even proof of concept is provided.

We also wanted to assess whether there were statistically significant associations between the four different quality aspects; therefore we carried out a Pearson's test, with Bonferroni correction, to measure the strength of association between the four aspects. The analysis was carried out using Stata, with $\alpha = 0.05$. Results are displayed in Figure 6, in which there are three values shown per pairwise correlation: The first is the correlation coefficient (an asterisk showed that the coefficient is statistically significant); the second is the p-value of the test, and the third is the sample size used. The results indicate that there are statistically significant positive associations between the four quality aspects; however the

Figure 5. Detailed 11 quality criteria, arranged according to four aspects

	repor~03	rigour05	credi~02	relev~01
reporting03	1.0000			
	143			
rigour05	0.4125*	1.0000		
	0.0000			
	143	143		
credibili~02	0.3524*	0.7313*	1.0000	
	0.0001	0.0000		
	143	143	143	
relevance01	0.3893*	0.4259*	0.3003*	1.0000
	0.0000	0.0000	0.0016	
	143	143	143	143

Figure 6. Detailed 11 quality criteria, arranged according to four aspects

highest correlation coefficient relates to the relationship between Rigor and Credibility (0.7313). Therefore, the higher the credibility of a paper, the higher its rigor, and vice-versa. The second highest correlation coefficient (but much lower than the highest) was obtained for Relevance and Rigor (0.4259); thus the higher the Relevance, the higher the Rigor, and vice-versa. It is important to note that the highest correlation coefficient was not given for Rigor and Relevance, which, in our view, suggests that the use of more detailed

quality measures, such as the one employed herein, rather than solely Rigor and Relevance, provides a better and more detailed understanding of studies' quality.

Summary of key findings:
1. The studies' quality criteria by Dybå and Dingsøyr [7], when applied to the 143 studies in this mapping study, showed that most studies presented good quality of reporting and relevance, acceptable credibility and poor rigor.
2. Many of the studies published within the period 2003 to 2016 were either proof of concept, or advocacy research-type papers; however since 2017 all studies presented evidence obtained by means of empirical investigations.
3. The Pearson's correlation analysis test showed a statistically significant high positive association between rigor and credibility.
4. Results indicated that empirically-based studies, and with higher quality in terms of rigor and credibility, are needed.

4.4. SE principles and practices (Research question 3)

What are the SE principles and practices investigated so far in VBSE, and how has this changed over time?
To answer this research question we used as basis the classification suggested in VBSE Agenda for existing and emerging SE principles and practices [1] (requirements engineering, architecting, design and development, verification and validation, planning and control, risk-management, quality management, people management, and Theory of VBSE), plus an additional four practices not included in the original agenda (value-based decision-making, software process, value creation and a fourth category called "Other", i.e., studies looking at general aspects of VBSE). These four additional classifications were added in order to better characterize some of the selected studies, and in line with their research descriptions. Figure 7 shows the number of studies arranged per SE principles and practices, and per the three different periods being covered (2003 to 2008; 2009 to 2014; 2015 to 2020), and

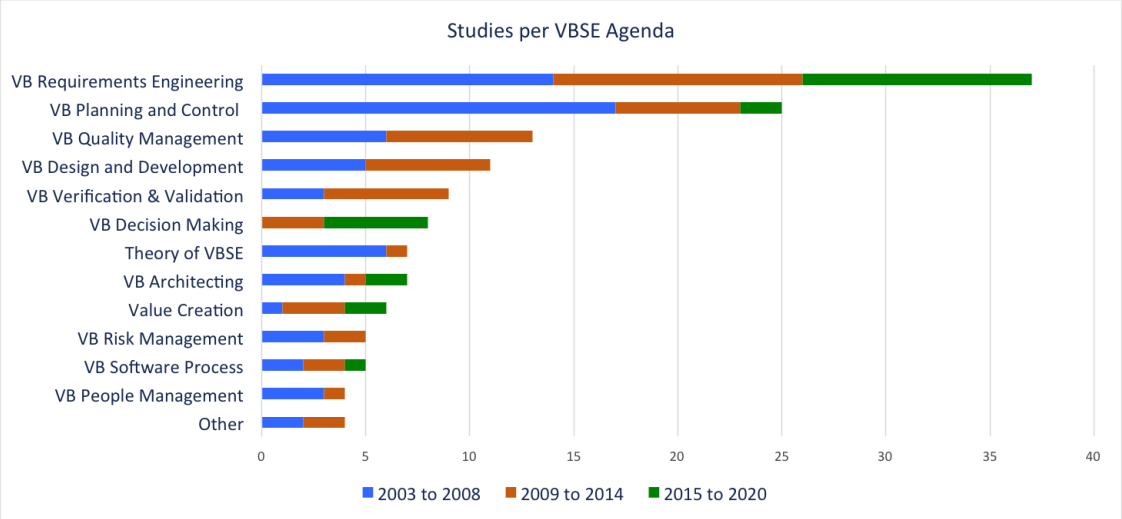

Figure 7. Studies per VBSE agenda

Table 6 provides further details relating to which studies belong to a given category, also arranged according to the same time periods. First, we will elaborate upon the overall results prior to discussing whether, and how, trends have changed over time.

Table 6. VBSE agenda

VBSE Agenda	Count	Paper ID
VB Requirements Engineering	37	2003 to 2008 (14) [S18], [S19], [S21], [S28], [S61], [S79], [S86], [S97], [S99], [S101], [S104], [S107], [S109], [S126] 2009 to 2014 (12) [S7], [S8], [S13], [S14], [S35], [S60], [S62], [S65], [S72], [S116], [S119], [S130] 2015 to 2020 (11) [S15], [S55], [S56], [S103], [S124], [S135], [S136], [S137], [S139], [S140], [S142]
VB Planning and Control	25	2003 to 2008 (17) [S20], [S23], [S24], [S30], [S32], [S39], [S40], [S70], [S75], [S92], [S51], [S68], [S81], [S96], [S105], [S111], [S134] 2009 to 2014 (6) [S36], [S43], [S95], [S118], [S123], [S131] 2015 to 2020 (2) [S108], [S141]
VB Quality Management	16	2003 to 2008 (9) [S16], [S17], [S22], [S31], [S41], [S53], [S57], [S74], [S94] 2009 to 2014 (7) [S10], [S11], [S113], [S114], [S125], [S27], [S91] 2015 to 2020 (0) none
VB Design and Development	11	2003 to 2008 (5) [S52], [S64], [S66], [S106], [S129] 2009 to 2014 (6) [S25], [S37], [S63], [S77], [S78], [S132] 2015 to 2020 (0) none
VB Verification and Validation	09	2003 to 2008 (3) [S46], [S71], [S100] 2009 to 2014 (6) [S6], [S59], [S73], [S83], [S93], [S98] 2015 to 2020 (0) none
VB Decision Making	08	2003 to 2008 (0) none 2009 to 2014 (3) [S84], [S88], [S90] 2015 to 2020 (5) [S34], [S54], [S112], [S117], [S143]
VB Architecting	07	2003 to 2008 (4) [S12], [S58], [S80], [S85] 2009 to 2014 (1) [S89] 2015 to 2020 (2) [S122], [S133]
Theory of VBSE	07	2003 to 2008 (6) [S1], [S48], [S49], [S50], [S69], [S76] 2009 to 2014 (1) [S4] 2015 to 2020 (0) none
Value Creation	06	2003 to 2008 (1) [S127] 2009 to 2014 (3) [S9], [S110], [S115] 2015 to 2020 (2) [S33], [S138]
VB Software Process	05	2003 to 2008 (2) [S42], [S44] 2009 to 2014 (2) [S5], [S87] 2015 to 2020 (1) [S120]
VB Risk Management	04	2003 to 2008 (3) [S29], [S47], [S102] 2009 to 2014 (1) [S121] 2015 to 2020 (0) none
VB People Management	04	2003 to 2008 (3) [S2], [S45], [S128] 2009 to 2014 (1) [S38] 2015 to 2020 (0) none
Other	04	2003 to 2008 (2) [S26], [S67] 2009 to 2014 (2) [S3], [S82] 2015 to 2020 (0) none

Results show that **VB Requirements Engineering (RE)** has been the mostly investigated principle and practice in VBSE, contributing with 37 studies (25.3%). Majority of the studies (17 studies) proposed a value-based method, or approaches for requirements prioritization. Other value-based approaches proposed include the areas of requirements elicitation, requirements tracing, RE process, requirements negotiation, and tool support selection. The second most investigated principle and practice in VBSE research is **VB Planning and Control**, with 25 studies (17.1%). Most studies (9 studies) under this category proposed value-based approach to support software project planning. The rest of the studies proposed value-based methods for software release planning, managing value delivered to stakeholders, value-based technique to better prioritize stakeholders' value, value-based approach to measure productivity, planning for software traceability, value assessment for software reuse, planning for measurement to support decision-making process, and value-based approach to determine an optimum software assurance investment.

The additional three (3) principles and practices that also received significant attention in VBSE research are VB Quality Management (16 studies), VB Design and Development (11 studies) and VB Verification and Validation (9 studies). Research in **VB Quality Management** mainly focused on software processes' quality aspects (4 studies). The remaining studies investigated the levels of alignment between key stakeholders on software quality aspects, value aspects of software quality assurance, tailoring the value-based software quality achievement process to different business cases, software quality investment, and assessment of quality processes. Research related to **VB Design and Development** involves techniques and approaches to ensure value-considerations are integrated into the software's design and development [1]. Three (3) out of 11 studies proposed value-based approach to support software component markets. The remaining studies proposed a design technique used to estimate the value of a design strategy, an approach to develop decision support systems, incorporating customers' value in the process of partitioning hardware and software for embedded system, managing inconsistencies in software development, and value-based technique to evaluate software designs. **VB Verification and Validation (V&V)** has been researched in nine (9) studies. Two (2) of these focused upon prioritization strategies to improve software testing cost-effectiveness. Others have proposed a value-based software testing method to better align investments with project objectives and business value, enhancement of V&V process, coverage measurement tool in software system testing, and software evolutionary testing framework using genetic algorithms. Two (2) experimental studies on VB V&V compared the performance of value-based review (VBR) with the traditional value-neutral checklist based reading approach.

We identified eight (8) studies on **VB Decision-Making** as an emerging research area in VBSE. Two (2) studies explored feature usage measures to support the decision-making process. Two studies introduced a VALUE framework to estimate the value associated with stakeholders' decisions. They also developed a Value tool to support the decision-making process. The other studies proposed a software value map for making decisions about product management and development, and empirical studies to validate models for estimating value of decisions, and assessment of a Web-based tool for value-based decision-making.

There are seven (7) studies found related to **VB Architecting**. Three (3) of these studies focused on value-based approach for documenting design-decisions rationale to support software architecture design. The remaining studies introduced: a customer-centric value for assessing system architecture investment, a lightweight value-based architecture evaluation, a value discovery method in the context of Big Data design, and a method to evaluate diversification of software architecture for software sustainability.

Three of the seven (7) studies classified under **Theory of VBSE** described the $4 + 1$ theory. One study [S4] made a proposal for extending the VBSE theory. The remaining three (3) studies present the VBSE agenda and the seven VBSE elements. **Value Creation** category comprises six (6) studies, in which the majority (4 studies) focuses on customer value creation in Agile context, while the others proposed a new definition of value, and an empirical study on how user perceived value impacts user loyalty for software product. Five (5) studies under the **VB Software process** mostly investigated value factors that can impact software development process and the factors were later used in building a framework for software process tailoring. Others had introduced vaue-based software process model for Europe, and a value-based set of processes for Components-Off-The-Shelf (COTS)-based applications.

Our results showed that VB Risk Management and VB People Management are the least investigated VBSE principles and practices (four (4) studies respectively). Studies related to **VB Risk Management** have proposed: valuation of software initiatives under uncertainty to help with decisions at the project level, a value-based process to manage requirements-related risks, a model to identify risk in architectural mismatches in component-based system development, and a method to assess uncertainties in software project. The four (4) studies classified under **VB People Management** described four different aspects: value-based knowledge management to support learning in software companies, value-based approach for managing architectural knowledge, collaborative process to facilitate stakeholders' involvement, and stakeholder value as a means to understand conflicts in software development.

The remaining four (4) papers in the **"Other"** category are general VBSE papers covering a framework to identify value of new innovation idea, applicability of Lean Six-sigma principles to be embedded in VBSE process, applications of machine learning methods in VBSE, and pedagogical game for teaching VBSE to students. Overall findings showed that most VBSE studies had focused on the early phases of software engineering activities, i.e., requirements engineering, and planning and control. While various value-based approaches and solutions have been proposed (as described above), initiatives to perform measurement of value in VBSE studies require further addressing. This is because such measurement is needed in various SE activities as a follow up on the generation of value.

When we look at the trends over the three different periods (in Figure 7), we see that the only VBSE principles and practices remained with a similar number of publications over all three periods has been VB Requirements Engineering. VB Planning and Control had the largest number of publications over the period 2003 to 2008, but then dropped by less than half over the next period (2009–2014) and down to two papers between the period 2015–2020. VBSE principles and practices not investigated during the most recent period (2015–2020) are VB Quality Management, Theory of VBSE, VB Design and Development, VB Verification and Validation, VB Risk Management, VB People Management, and Other. Such lack of recent studies in areas that are still relevant within SE suggests possible research gaps that could be investigated by the VBSE community. VB Decision Making only emerged, as far as publications are concerned, over the two most recent periods, with an increase in publications over the most recent period (2015–2020). Both Theory of VBSE and VB People Management had by far their largest contribution in number of publications during the first period 2003–2008.

The overall trends of publications based on VBSE principles and practices can be seen in a bubble plot (see Figure D1 in Appendix D). In the bubble plot, the size of a bubble indicates the amount of papers published and the number near a bubble represents the

number of publications. Based on the number of publications, the trend indicates that there is a constant interest in VB Requirements Engineering research, followed by VB planning and control, and Value creation. VB quality management is also an area that had some interest up to 2014. Other principles and practices that had publications for at least four years (not necessarily consecutive years), but later discontinued, are VB verification and Validation, VB Software Process, VB design and development, VB architecting, Theory of VBSE, and Other. As previously mentioned, the only emerging area is VB decision making, with publications since 2013. Finally, principles and practices that had publications for three years (not necessarily consecutive years) are VB risk management and VB people management.

We observed that the last year in which there were papers co-authored by Barry Boehm was 2013, and from that point onwards there was a decline in the number of papers that considered value aspects as per the value-based principles defined by [1]. This was observed very clearly for those seven principles and practices abovementioned, for the most recent period (2015–2020). However, this does not necessarily mean that VBSE is not important, or that value-based research in SE ceased to receive attention. Some of the VBSE principles and practices may have been adopted by the Lean and Agile Software development communities for example through a continuous value delivery practice as highlighted in [30], while others may perhaps be the focus of some research that does not explicitly reference Barry Boehm's work in VBSE. An additional point to stress here is that despite our use of number of publications to suggest research gaps, the number of publications is not the only factor to identify gaps. There is a need to determine (a) is research needed where there are few publications and (b) are areas with many publications still supported by credible evidence, considering studies' quality. With regard to the latter point, it was discussed in detail by RQ2.

Summary of key findings:
1. The main emphasis of VBSE research is placed on the early phases of software engineering, i.e requirements engineering and software planning/control.
2. Within RE, the main concern of investigations was placed on using value in the prioritization of requirements.
3. Not much is known on how values can be incorporated in SE practices to analyze, prioritize and mitigate risks that occur in software project (VB Risk Management).
4. There are lack of studies in the areas of VB Risk Management and VB People Management.

4.5. Research topics (Research question 4)

What are the most investigated research topics in VBSE, and how has this changed over time?

To answer this research question, we referred to the twelve (12) Knowledge Areas identified in SWEBOK [24] (e.g., software requirements, software design, software construction, software testing, etc.). The result showed that Software Requirements and SE Management were the two topics that have been actively researched in VBSE (34 and 30 studies respectively). Within the Software Requirements category, most studies (17 out of 34 – 50%) focused on issues related to requirements prioritization. Studies within the SE Management category focused on different management aspects mainly decision value/analysis (6 studies), and

product value estimation and planning and control (4 studies each). Our findings showed that very few studies fell under the SE Professional Practice (3 studies), Software Maintenance (2 studies), and Software Construction (1 study) Knowledge Areas. It is interesting to note that there are no studies available particularly addressing the SWEBOK Knowledge Areas of Configuration Management, Computing and Mathematical Foundations.

With regard to changes in VBSE research topics over time (see Figure 8), six topics showed some consistency in the number of studies for the first two time periods (2003 to 2008; 2009 to 2014): Software Requirements, Software Quality, SE Process, SE Models and Methods, SE Management and Engineering Foundation. However, except for Software Quality and Engineering Foundation, which did not have any studies published within the period 2015–2020, all four remaining topics dropped their number of studies published within the period 2015–2020 by half or even less than half. The SE Professional Practice topic only had studies published within the period 2003–2008, and Software Construction only had one study published, and in the period 2015–2020. The topic Software Maintenance only had studies published within the two most recent periods. Despite the drop in the number of studies over the most recent period 2005–2020, there are nine topics, out of the 12 topics, which had at least one study published over the most recent period. Overall, the two topics Software Requirements and SE Management showed the highest numbers of publications for all the three periods covered, thus suggesting a continued interest from the research community in these two topics. The detailed list of research topics addressed by our primary studies is available in Appendix C.

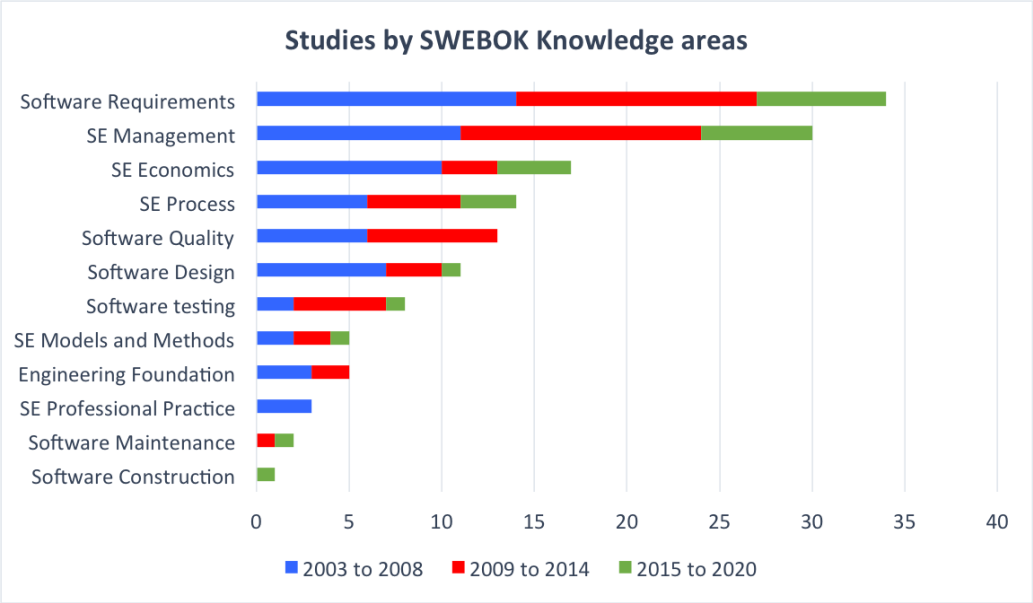

Figure 8. Research topics trend over time

Summary of key findings:
1. Most of the VBSE research topics fall within the area software requirements, mainly requirements prioritization.

2. Majority of the topics (9 out of 12) had at minimum one publication over the most recent period, suggesting that the topics are still active (despite low number).
3. Topics related to software maintenance, software construction and SE Professional practice have received less attention despite being important areas in SE.

4.6. Research methods (Research question 5)

What are the research methods used in VBSE studies and how many studies looked at each method (e.g., case study, experiments, survey, etc.)?
This research question aims to identify the research method(s) employed in the primary studies included in this mapping study. We used the classification of research methods as reported in [26, 27]. The bar chart in Figure 9 shows the distribution of studies by the research method.

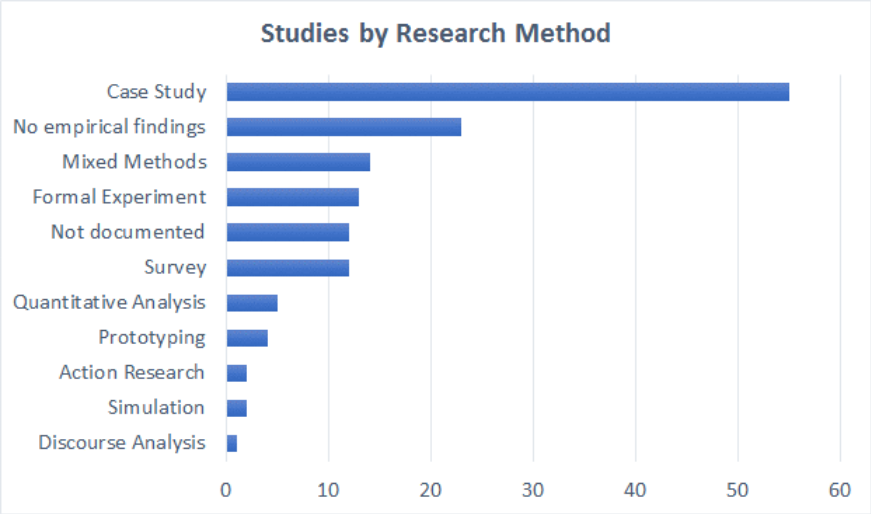

Figure 9. Studies by research method

Our analysis showed that most studies (38%, 55 out of 143) were conducted using a case-study methodology. Forty-two (42) of these studies reported their case study within an organizational context (e.g., defence agency, software organization, startup company and large company such as Ericsson). After case studies, the second largest category (23 studies) related to studies that did not report empirical findings. They proposed solutions without empirical validation or evaluation (e.g., [S6], [S46], [S62]). Next, we had, Mixed methods (14 studies), Formal experiment (13 studies), Not documented (12 studies), and Survey (also 12 studies). Finally, the last five categories with low number of studies were Quantitative analysis, Prototyping, Action research, Simulation, and Discourse analysis.

The breakdown of studies according to the study context is available in Table 7. Studies that have used more than one research method were classified under the mixed-methods category. Case study is by far the research method used the most, and most of the case studies were carried out within an organizational setting. Similar to case study research, mixed methods and survey studies were also commonly conducted in organizational context. Studies that have used formal experiments mostly conducted their research in academic context. A total of 23 studies did not report any empirical findings but have documented

their context; most were conducted within an organizational context. Finally, there are a small number of studies that performed simulations, discourse analysis, and action research. Analysis based on VBSE Agenda indicated that, except for VB quality management, VB people management, and VB decision making, all the other principles and practices had at least one study that had no empirical findings. This corresponds to 16% of the included studies, which, in our view suggest that future research should focus upon widening the number of studies with empirical investigations within the context of VBSE.

Summary of key findings:
1. Most of the VBSE research were conducted using case-study methodology.
2. Research conducted in industrial and organizational context commonly applied case study, mixed-method, and survey methodology.
3. Formal experiments are mostly conducted in academic setting.
4. More empirical studies are needed to validate the proposed solutions; particularly there is a lack of experimental study in industrial or organizational setting.

4.7. Research types (Research question 6)

What are the research types that these studies apply (e.g., validation/evaluation/solution proposal, etc.) and how many studies looked at each research type?

In answering this question, we referred to the existing types of research approaches as suggested by [27] for making the classification. The number of studies identified for each research type is depicted in Figure 10. Our analysis showed that most studies (42 out of 143, 29%) proposed solution technique(s) without any empirical validation or evaluation. Second came studies (39 studies) that presented solution proposal together with the validation strategy. Studies that performed evaluation and validation comprised 14% and 13%, respectively. The remaining studies, less than 5% each, were categorized into philosophical paper, solution proposal and evaluation, experience report, opinion, and literature review. The breakdown of studies for each research type can be seen in Table 8.

An overview of publications across the two dimensions VBSE agenda and research type shows that there are four research types that have been used the most: i) Solution proposal, employed in 42 studies that focused on VB design and development, VB planning and control, and VB requirements engineering, ii) Solution proposal and Validation, used by 39 studies, mainly on VB requirements engineering and VB planning and control, iii) Evaluation, used in 20 studies, mainly from the VB requirements engineering topic, and finally, iv) Validation, employed in 18 studies of VB requirements engineering as well. The two research types used the least were Literature review (1 study) and Opinion paper (3 studies).

Majority of the evaluation and validation studies (25 studies) were conducted in organizational context, followed by industrial (9 studies) and academic settings (2 studies). The research methods employed for evaluation studies consist of survey, case study, and mixed-method, whereas for validation studies, most (10 studies) were conducted using case-study method, followed by experiment (4 studies) and mixed-method (3 studies). We also found that experimental type of studies have only been used in validation studies. For example, in [S73], the experiment involving graduate software engineering team project course was conducted to compare the effectiveness of value-neutral and the proposed value-based artifact priorization process.

Table 7. Breakdown of studies by research method

Research Method	Study Context					
	Organization	Academic	Industry	Govt	Not reported	Total
Case Study	[S8], [S9], [S10], [S14], [S18], [S19], [S21], [S23], [S24], [S30], [S31], [S39], [S40], [S41], [S43], [S50], [S53], [S56], [S60], [S61], [S68], [S70], [S72], [S76], [S79], [S83], [S84], [S86], [S88], [S89], [S91], [S93], [S98], [S103], [S105], [S115], [S117], [S119], [S121], [S122], [S123], [S131]	[S29], [S95], [S109], [S34]	[S102], [S108], [S130], [S142], [S140], [S143]	–	[S17], [S64], [S133]	55
No empirical findings	[S6], [S13], [S20], [S25], [S42], [S48], [S51], [S59], [S69], [S81], [S82], [S85], [S110], [S118], [S120], [S132]	[S26]	[S49], [S101], [S106]	–	[S46], [S47], [S62]	23
Mixed Methods	[S57], [S65], [S74], [S90], [S99], [S100], [S112]	[S136], [S139], [S141]	[S54], [S104]	–	[S1], [S16]	14
Formal Experiment	[S11], [S12], [S58]	[S35], [S71], [S73], [S80], [S135], [S137], [S138]	[S116]	–	[S38], [S92]	13
Not documented	[S3], [S4], [S5], [S32], [S44], [S113], [S114], [S127]	–	[S129]	–	[S37], [S94], [S96]	12
Survey	[S7], [S27], [S28], [S125]	[S15], [S33]	[S55], [S97], [S107], [S126], [S128]	[S87]	–	12
Quantitative Analysis	[S22], [S75], [S134]	[S124]	–	–	[S66]	5
Prototyping	[S36], [S63]	[S67]	[S78]	–	–	4
Action Research	[S2]	[S45]	–	–	–	2
Simulation	[S52], [S111]	–	–	–	–	2
Discourse Analysis	–	–	[S77]	–	–	1

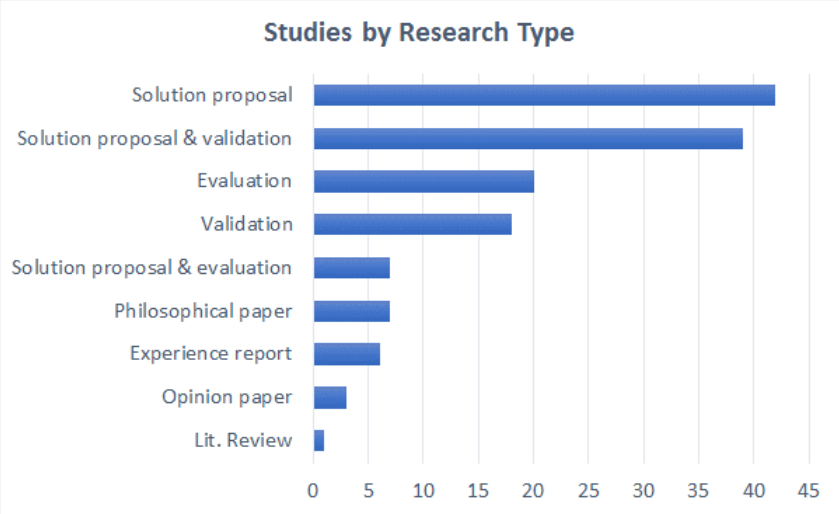

Figure 10. Studies by research type

Table 8. Breakdown of studies by research type

Research Type	Studies	Total
Solution Proposal	[S2], [S3], [S5], [S8], [S13], [S20], [S22], [S25], [S32], [S36], [S37], [S42], [S44], [S45], [S46], [S51], [S52], [S54], [S59], [S62], [S63], [S64], [S66], [S67], [S74], [S78], [S81], [S92], [S101], [S106], [S110], [S111], [S118], [S120], [S124], [S127], [S129], [S132], [S134], [S137], [S140], [S142]	42
Solution Proposal and Validation	[S6], [S11], [S12], [S14], [S15], [S17], [S18], [S23], [S24], [S29], [S31], [S35], [S38], [S39], [S40], [S41], [S43], [S68], [S71], [S76], [S79], [S80], [S83], [S84], [S86], [S93], [S95], [S96], [S102], [S103], [S109], [S122], [S123], [S133], [S135], [S136], [S139], [S141], [S143]	39
Evaluation	[S7], [S10], [S16], [S27], [S28], [S30], [S33], [S55], [S87], [S88], [S91], [S97], [S104], [S107], [S108], [S115], [S119], [S125], [S126], [S128]	20
Validation	[S34], [S53], [S56], [S57], [S58], [S60], [S61], [S65], [S70], [S72], [S73], [S75], [S105], [S112], [S116], [S117], [S121], [S138]	18
Philosophical Paper	[S1], [S47], [S48], [S49], [S50], [S69], [S77]	7
Solution Proposal and Evaluation	[S9], [S19], [S21], [S89], [S90], [S98], [S100]	7
Experience Report	[S4], [S85], [S113], [S114], [S130], [S131]	6
Opinion Paper	[S26], [S82], [S99]	3
Lit. Review	[S94]	1

Summary of key findings:
1. The most common research type in VBSE is solution proposal (comprised 61% of the studies), and almost half of these studies did not perform any empirical validation or evaluation.
2. Research methods used for empirical evaluation studies are mainly survey and case study.
3. Evaluation studies performed in industrial context have used survey as their research method.

4. Majority of the studies proposed solution without empirical validation or evaluation. This implies that there is a lack of maturity in implementing the solutions in practice and lack of evaluation involving practitioners in the real-world industrial context.

4.8. Contribution facets (Research question 7)

What contribution facets do they provide (e.g., process, method, model)? The contribution facets for each study were classified according to the contribution types suggested by [23] (see Figure 11). The facets herein referred to the contribution type or the kind of intervention being studied such as the process, method, tool, metric or model [23]. Results showed that most of the contribution facets were provided as methods (32 studies, 22.3%) followed by processes (31 studies, 21.6%), and models (24 studies, 16.7%). Next we had Frameworks (11 studies, 7.6%), Other/Tool/Metric all with 8 studies each (5.6%), Techniques (7 studies, 4.8%), Model and Tool (6 studies, 4.2%), Process and Tool/Method and Metric both with 3 studies each (2%), and finally Metric and Tool with 2 studies (1.3%).

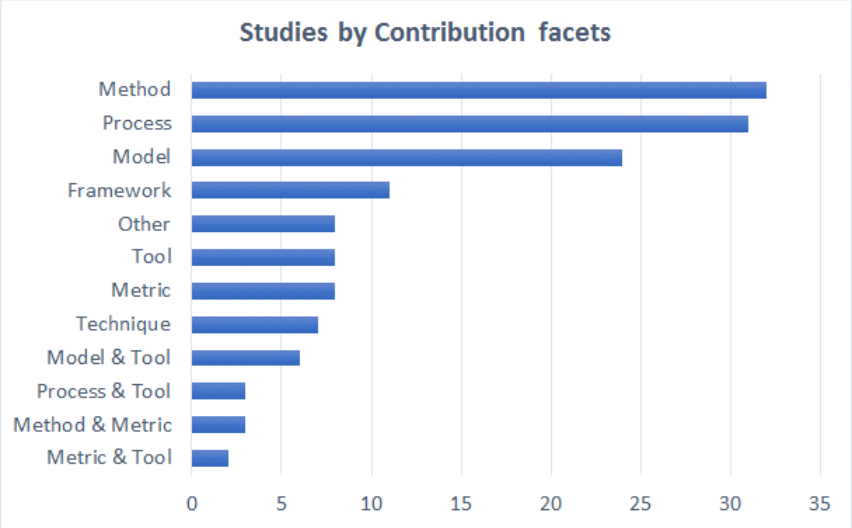

Figure 11. Contribution facets

Table 9 shows the breakdown of studies for each contribution facet. Note that while performing the mapping, we did our best to use the same facet term as identified in the paper. For example, in [S14] and [S70], the authors used the term "technique" to specify their contributions; hence, we categorized them under the "technique" category, and so on. In some studies, the authors described more than one type of contribution (e.g., [S74], [S65]). For example, [S74] proposed a quality model and a tool known as ODC-COQUALMO (Orthogonal Defect Classification COnstructive QUALity MOdel) to decompose the defect types into more granular ODC categories. Therefore, we classified this study under the model and tool category. A total of 31 studies offered a variety of solutions for improving SE processes by incorporating VBSE elements. [S11] for instance proposed an approach to transforming value-neutral processes into value-based software development processes, while [S42] presented value-based processes for COTS-based applications. A method usually

has a more specific goal and a narrow purpose or research question [31]. Most of the studies that suggested a method, focused on the effort to support requirements prioritization for elicitation and reconciliation of stakeholder value propositions. For example, [S8] put forward a method to prioritize requirements using decision theory, whereas [S24] presented a prioritization method (impact estimation) to better capture explicit stakeholder value and to cater for multiple stakeholders.

Table 9. Breakdown of studies by contribution facets

Contribution Facets	Studies	Total
Method	[S2], [S8], [S9], [S12], [S13], [S20], [S21], [S24], [S32], [S33], [S35], [S37], [S39], [S40], [S55], [S64], [S66], [S80], [S83], [S91], [S93], [S96], [S99], [S10], [S94], [S116], [S120], [S122], [S126], [S133], [S139], [S142]	32
Process	[S7], [S11], [S19], [S29], [S41], [S42], [S44], [S45], [S50], [S53], [S58], [S61], [S82], [S97], [S86], [S73], [S79], [S71], [S76], [S81], [S30], [S27], [S104], [S105], [S107], [S110], [S115], [S119], [S123], [S125], [S131]	31
Model	[S17], [S18], [S22], [S23], [S34], [S48], [S51], [S56], [S62], [S68], [S69], [S75], [S89], [S92], [S101], [S106], [S109], [S111], [S112], [S118], [S132], [S134], [S136], [S138]	24
Framework	[S3], [S5], [S15], [S43], [S46], [S59], [S77], [S85], [S31], [S16], [S141]	11
Tool	[S6], [S36], [S60], [S67], [S103], [S117], [S129], [S143]	8
Metric	[S87], [S88], [S90], [S108], [S113], [S114], [S127], [S128]	8
Technique	[S14], [S70], [S52], [S124], [S135], [S137], [S140]	7
Model and Tool	[S54], [S57], [S63], [S74], [S78], [S102]	6
Method and Metric	[S95], [S98], [S121]	3
Process and Tool	[S100], [S84], [S38]	3
Metric and Tool	[S65], [S72]	2

The contribution facet categorized as model refers to the abstract classification or model of a problem or topic, rather than to a specific tangible way of solving a problem [31]. There appears to be a number of studies presenting models – a value-driven (V2) model to elicit customers' value from requirements analysis, ROI model (iDAVE) to estimate future investment on software dependability, and value-based software assurance model to assess relative payoff of value-based vs. value neutral testing, to name a few. Our results also showed that several studies proposed a framework as their contribution facet. A framework differs from a method in the sense that it represents a detailed methodology that may include several methods, in addition to having a wider purpose and focusing on several research questions or areas [31]. An example of such a framework is the Value Elicitation Framework, proposed by Murtaza et al., 2010 [S43], which aims at facilitating the selection and application of value elicitation techniques in a project lifecycle. Zhang (2013) [S59] also describes a value-based framework that focuses on test data generation through genetic algorithms and helps prioritize decisions in the testing process.

Further, results also highlighted that some studies developed a tool for evaluating or validating proposed concepts or solutions related to processes, models, and metrics. As an example, Madachi et al., 2007 [S100] developed a software risk advisory tool using ODC COQUALMO quality model to optimize V&V processes for NASA flight projects. The "Other" contribution facets comprised a wide array of approaches that have been recommended in the identified studies, which did not relate to process, method, tool, technique, model, framework, or metric. As an example, [S4] presented an analysis of

software implementation projects for assessing the applicability of a value-based approach. When analyzing based on VBSE research agenda and research type, we found the following main aspects:

- Most studies in VB Requirements engineering used the research types Solution Proposal and Validation, Evaluation, Solution Proposal, and Validation. Regarding their types of contribution, the highest number of studies contributed towards Methods (10 studies), Processes (9 studies), Models (6 studies), and Techniques (5 studies).
- Most studies in VB planning and control employed the research types Solution Proposal and Validation and Solution proposal. Their main types of contribution were towards Models (8 studies), Methods (6 studies), and Processes (5 studies).

The results also suggest a relationship between the use of research types Solution Proposal, Solution Proposal and Validation, Evaluation and Validation with focused contributions towards Methods, Processes, Techniques and Models (see bubble plot in Appendix D). This is also supported by many other research facets and types, such as VB quality management, VB Software Process, VB design and development, VB Architecting, and Value creation. The contribution facets the least investigated were Method and Metric (3 studies), Process and Tool (3 studies), and Metric and Tool (2 studies).

Summary of key findings:
1. The contribution facet of VBSE research is mostly of method type.
2. Most research efforts is spent on value-based requirements engineering and planning and control with contributions mainly on methods, processes, and models.
3. Despite the higher number of studies contributed towards methods, processes and models, their contributions appear as proposed solution, and yet to be evaluated.
4. Contributions in terms of the proposed method, process, and model need to be supported by tools for practical use, and metrics for evaluation or measurement.

4.9. Publication venues (Research question 8)

RQ 8: What are the publication venues for VBSE research?
Most of the included studies were published in conference proceedings (88 out of 143, 61%), followed by journal articles (37 studies, 26%), and book chapters (18 studies, 13%) (see Figure 12). In relation to the book chapters, twelve (12) of these were published in the VBSE book [2]. For journal articles, we found 37 journal articles published in 22 venues.

Table 10 shows the journals where at least two VBSE studies were published. As can be seen, most journal articles were published in IEEE Software (7 out of 37 journal articles), followed by Information and Software Technology (4 articles), and the Journal of Software-Evolution and Process (3 articles). Next, there are four journals that have published 2 articles each and there are another 15 journals that have published one article each.

Table 11 lists the conferences where most primary studies were published. We only list venues in which more than one primary studies were published. In total, our review included 88 conference papers, and 42 venues where only a single primary study was published. Results showed that ESEM and EUROMICRO were the two (2) top conferences that published VBSE research, each with 6 papers. We identified three (3) conferences listed in Table 11 that are no longer active: EDSER, ASWEC, and IASTED SE. EDSER used to be one of the important venues that published VBSE studies in the early 2000,

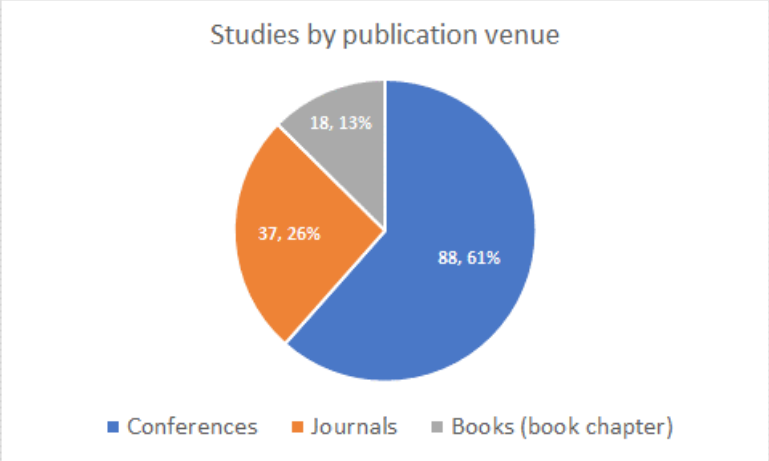

Figure 12. Number of studies by publication venues

Table 10. Classification by journals

Journal Name	Study(s)	#Studies
IEEE Software	[S7], [S19], [S22], [S23], [S42], [S61], [S102]	7
Information and Software Technology	[S91], [S108], [S135], [S138]	4
Journal of Software-Evolution and Process	[S83], [S90], [S141]	3
Software Process Improvement and Practice	[S31], [S44]	2
Software Quality Journal	[S112], [S128]	2
SIGSOFT Software Engineering Notes	[S1], [S105]	2
Requirements Engineering Journal	[S15], [S139]	2

co-located with the International Conference on Software Engineering (ICSE), a premier SE conference. The last EDSER proceedings were published in 2007. Meanwhile, the last conference for ASWEC was held in 2018, while for IASTED SE, the last conference was held in 2016.

We also analyzed the trend of publications by venue, contribution facets, and the VBSE areas (see bubble plot in Figure D5, Appendix D). Most conference papers published VBSE research in VB requirements engineering (24 studies), VB planning and control (15 studies), VB quality management (10 studies), and VB design and development (8 studies). Regarding journal publications, they focused on publishing research in two areas: VB Requirements Engineering (11 studies) and VB Planning and Control (8 studies). Finally, book chapters were published in nine different areas, with the largest number of studies in Theory of VBSE (4 studies).

Summary of key findings:
1. Most journal papers were published at IEEE Software, i.e., a magazine that targets at practitioners willing to understand applied research.
2. Only two of the 36 traditional academic journals had at least three papers published, hence suggesting a high diversity of venues for VBSE research.
3. The highest number of VBSE conference papers published in these two conferences: ESEM and EUROMICRO SEAA.

Table 11. List of publication venues (conferences)

Publication Venue	Description	Studies	Total
ESEM	Empirical Software Engineering and Measurement	[S39], [S71], [S75], [S97], [S113], [S123]	6
EUROMICRO SEAA	EUROMICRO Conference on Software Engineering and Advanced Applications	[S6], [S16], [S20], [S21], [S104], [S117]	6
EDSER	International Workshop on Economics Driven SE Research	[S69], [S111], [S132], [S134]	4
SEKE	Software Engineering and Knowledge Engineering	[S25], [S26], [S32], [S37]	4
PROFES	International Conference on Product Focused Software Development and Process Improvement	[S95], [S3], [S77], [S115]	4
ICSE	International Conference on Software Engineering	[S8], [S57], [S58]	3
ICSSP	International Conference on Software and System Process	[S98], [S73], [S35]	3
RE	Requirements Engineering Conference	[S65], [S119]	2
ICSP	International Conference on Software Process	[S74], [S93]	2
ICGSE	International Conference on Global Software Engineering	[S9], [S10]	2
ASWEC	Australasian Software Engineering Conference	[S84], [S87]	2
IASTED SE	IASTED International Conference on Software Engineering	[S29], [S38]	2
ACIS SNPD	Int'l Conf. on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing	[S12], [S64]	2
CSER	Conference on Systems Engineering Research	[S72], [S114]	2
ICEIS	International Conference on Enterprise Information Systems	[S68], [S106]	2

42 more venues with one (1) paper.

5. Discussion

5.1. Rigour and credibility issues

Prior to providing a more detailed discussion about the findings from this mapping study, with regard their implications for research and practice, we first discussed the studies' quality in relation to the publication type. Our findings clearly show that most conference papers and book chapters presented unsatisfactory or poor rigour, and acceptable credibility (illustrated as bubble plot in Figure D7, Appendix D). A few journal papers also presented poor rigour and acceptable credibility, although a higher number of journal papers present very good rigour and good credibility. With regard to journal papers, most of those showing a lower rigour and credibility failed to address criteria 6, 8 and 9; whereas regarding conference papers and book chapters, other criteria were also not addressed. The fact that

many conference papers, and even some book chapters, provided only proof of concept examples contributed significantly to their quality being assessed as lacking. All the recently published VBSE papers were empirical studies, using industrial data to assess their proposals. Many, however, are not formal experiments; therefore we believe that criterion 6, which is part of rigour, could be revisited so to also cater for other types of empirical investigations. There were also some conference papers that showed Unsatisfactory quality for Relevance. These were the 20 studies that did not even provide an example to what they were proposing. The only aspect that showed positive results for all types of publications was reporting. However, there were still 32 conference papers that had good reporting. These results, in our view, send a strong message to the VBSE community about the need to increase the rigour and credibility of VBSE studies. Conference papers also need to add additional care on the quality of their reporting and the relevance of their findings for research and/or practice.

5.2. Practical and research implications

In this Section we discussed the implications of this mapping study findings for research and practice. Except for the discussion on quality of studies (presented above), we organize the discussion based on the RQ's topic:

Value Definitions. We found that the term "value" has not been clearly or explicitly described in many VBSE studies, except for the 10% of the primary studies. VBSE authors generally regarded "value" from the perspective of worth, or utility, and not solely on economic or monetary value. Although most of the studies refer to the VBSE defined in [1] and/or [2] when describing the context of value presented in their study, the multi-dimensional perspectives of value make it difficult or challenging to measure value. Misalignment of stakeholder interest, for instance, could potentially negatively affect value because value should be measured at organizational level and therefore must be agreed upon by principle stakeholders [S47]. Hence it is important for the practitioners to do proper elicitation and reconciliation of stakeholder value propositions to avoid conflicts. Further, the difficulty for practitioners to deal with varying notions of value concept also hinders the development of software system and its features. Implication for research would be to direct research efforts towards collaborating with practitioners in developing tool support by incorporating certain specified values in software system development. This is also highlighted by Shahin et al. [32] in their study on operationalizing human values in software engineering.

Another effort that could be taken is to develop relevant measures or metrics that can be used in practice for validating values operationalization. For example, [33] developed a systematic method based on Real Option approach to manage the high level of uncertainties in requirements decision as well as to manage Technical Debts in requirements engineering. Tsilionis et al. [34] proposed a conceptual framework called "Strategic Agile Model Driven IT Governance" to ensure evaluation of value from the strategic to management level can be performed. They specifically consider three different types of value (strategic, stakeholder and user value) that could be impacted by the development or adoption of new technologies particularly in a highly dynamic business context. The complexity of measuring value is also due to the understanding that value could go beyond the monetary or utility function, e.g., value as personal attitude or beliefs, politics, culture, emotion, etc., as reported in [S139] and [S15]. [S139] developed a value-based requirements engineering method to assist the elicitation of stakeholder's value and motivation that are related to socio-political

issues in software development including the stakeholders' potential emotional reaction to system change. From our findings, we observed that measuring human related values has not received adequate attention as more research efforts focused on the utility and/or economic value of a software product or services. Ignoring human values in software development might result in user dissatisfaction and negative socio-economic impact as highlighted by [35]. Their findings showed that only a small proportion of SE research (in SE top-tier venues) directly consider human values. They mentioned, "Whilst some values (such as privacy, security, and accessibility) are well embedded in SE methods, others (such as integrity, compassion, and social justice) have received less attention". Hence, future research may consider to integrate human values in software development.

SE Principles and Practices. We identified that VB Requirements Engineering as the significant area constantly being researched since 2003. A total of 37 studies focused on various topics related to integrating value perspectives in requirements engineering, particularly looking at requirements prioritization, and contributing towards Methods, Processes, Models and Techniques. The findings indicate that VBSE research mainly focused on the early phases of software engineering (i.e., requirements engineering and software planning/control). This is because there is a lot of interest in capturing stakeholders value proposition that mostly happened at the early stage of software development project (e.g., requirements elicitation) particularly in determining the features or functionalities that should be prioritized as well as identifying the "realized value" or benefits from the software product or services [36]. Not much is known on how values can be incorporated in SE practices to analyze, prioritize and mitigate risks that occur in software project (VB Risk Management). Similarly, how VBSE can stimulate stakeholders to achieve more compatibility and improvement in terms of participation in decision making, development of shared goals and mutual trust are some new areas that can be studied, i.e., VB People Management.

Other than the VBSE domain, value consideration in software development has also been the topic of interest particularly in agile and Lean software development research (e.g., [37, 38]). According to Lane et al. [37], Lean refers to a broader concept that considers software development from the overall business perspective concentrating on the customer-defined value and waste reduction initiatives. It is interesting to note that while studies in Lean consider value end-to-end, findings from our mapping study indicate that VBSE studies focus mainly on the early phases of software development.

Our findings also indicated that since 2017 the number of publications that considered value aspects as per the value-based principles defined by [1] has declined. This might be due to the changes in the value-based research landscape, where the value concepts have been taken from different dimension since the introduction of "Value-First SE" by Ferrario et al. [39]. Value-First SE specifically uses human values as their reference framework for decision making in each software development stages. Undeniably, the emergence of unethical incidents such as the Facebook-Cambridge Analytica scandal [40] has raised the concern to embed the principles of human values in SE decision making process. Consequently, more publications on this arena have appeared, such as in Winter et al. [41], Whittle et al. [42], Ferrario et al. [43], Hussain et al. [44].

Research Topics in VBSE. We found that most of the research topics of VBSE studies fall within the area of software requirements. This finding is expected, given the large number of studies available under the VB requirements engineering domain. The fact that most VBSE studies appear under the umbrella of Requirements Engineering is inline with the results from a mapping study by [45] that showed an increasing number of SE

taxonomies in the Requirements Knowledge Area. They observed that there is a rising trends in publishing as well as utilizing SE taxonomies in recent years, particularly in the area of software requirements. Taxonomies in SE have been utilized to better structure the SE body of knowledge based on a systematic classification scheme [45].

We also observed on the low number of studies under the software maintenance topic. This is interesting as we noticed that similar findings appeared in a systematic review by [25]. They conducted a review on global software engineering, also using SWEBOK to categorize the research topics. They mentioned, "Even more notably there were no studies particularly addressing the SWEBOK knowledge areas of software construction, maintenance and configuration management, and hence these areas have been skipped in the figure." (p. 103). We highlighted as a research gap, the need to look into the areas related to software maintenance, software construction, and SE professional practice as these are recognized as important knowledge areas in software engineering according to SWEBOK [24].

Research Methods used in VBSE. Our findings indicate that case study research has been employed in most of the VBSE studies. This is not suprising, given the findings from a mapping study by [46] that showed a large number of methodological support (e.g., guidelines, supporting instruments) exists to assist researcher in performing case-study research. Their study provides a catalog of research guidelines, assessment instruments, and knowledge organization system for researcher to conduct and evaluate empirical research in SE. Molléri et al. [46] also asserted that case study methodology "is well suited for many SE research topics, as it addresses a contemporary case in depth. It aims to understand the particular case and create the basis for further research on the topic" (p. 123). We observed from this mapping study quite a large number of VBSE studies that actually did not provide empirical findings (either through validation or evaluation), hence limiting the opportunity to compare the proposed solutions. Implication for research would be to suggest SE researcher to perform necessary validation (at least) or evaluation (in real setting) on their proposed solution. Such initiatives would help increase the quality of the proposed solutions and provide better support to industrial practitioners.

Research Types in VBSE. We found that the most common research type in VBSE is solution proposal (comprised 61% of the studies), and almost half of these studies did not perform any empirical validation or evaluation. Therefore, further validation and evaluation of such proposals could be a research gap. There is also a lack of evaluation using experimental method, particularly in industrial setting. This might be due to the difficulties to arrange and conduct the experiment involving practitioners or real users. Experimental results are deemed important to enable practitioners to evaluate the proposed technique or solution, and to determine the claims made about a particular proposed solution [47]. Practitioners' commitment to participate in the evaluation studies is crucial to ensure success of a study.

Contribution Facets. VBSE research presents their contributions mostly in terms of method. Although there is a high number of a study contributed towards methods, as well as processes and models, the contributions actually appear in the form of solution proposals, which are yet to be evaluated. One notable research gap would be to develop support tools that can be used to utilize the proposed method, process, or model, which would further enable practical use of the solution, and to develop relevant metrics for evaluation or measurement purposes. Implications for practice: There have been several processes, models, and methods within VBSE studies, which can be beneficial to practitioners or

organization that currently employ VBSE principles and practices, or that are willing to use them.

Publication Venue. Our findings indicate that VBSE studies were published in various venues, mainly conferences. This is probably due to a shorter timeframe to publish in conference proceedings, when compared to journals and book chapters. Some conferences are no longer active (e.g., EDSER, IASTED SE), however premier conferences such as ESEM are EUROMICRO SEAA are still available and published VBSE related research.

5.3. Threats to validity

We have used the guidelines for reporting threats to validity for secondary studies in SE by [48]. The discussion is arranged according to the following issues: i) need for the mapping study; ii) study selection, iii) data; and iv) research.

5.3.1. Threats to validity relating to the need to conduct this mapping study

Prior to carrying out this mapping study we searched on online databases (e.g., Scopus) so to check whether there was already a mapping study or systematic literature review covering the entire field of VBSE. None were found. We initiated this work in 2016, and the second author was already aware of the fully refereed related studies that were described in Section 2.3 – [11, 12] and the grey literature [14]. The field of VBSE is an important area to SE, in particular in light of many organisations that work within a market-driven context in which different stakeholders participate in many of the decisions relating to software/software-intensive products (e.g., [4, 11]). Therefore, it was clear that the mapping study detailed herein would make a clear research contribution to VBSE.

5.3.2. Threats to validity relating to study selection

With regard to the search string and the strategy employed in this study, we used numerous synonyms around the terms value-based software engineering. There was a sub-string (``economics based'' OR ``decision making'' OR economics OR ``software project'') that was also added to our search string because it was anonymously and strongly suggested by researchers in the VBSE domain. Perhaps the final string used was quite complex; however, all the important terms were included, using several combinations of OR and AND. We also had to make a pragmatic decision in relation to the cut-off date, as initial searches showed that there would be a large number of articles to screen through, and indeed the screening, extraction of data, synthesis of results, interpretation, and writing-up has taken more than 18 months to finalise.

We screened through 6,536 titles and abstracts, which, despite the length or time needed for screening, provided us with confidence about retrieving a significant and representative sample of studies in VBSE. As we only included studies written in English, we cannot argue that our mapping study covers all studies in VBSE. Furthermore, we conducted two phases of search, which included electronic search using online databases and snowballing (backward) search. Based on the manual filtering of 3273 references from 126 primary studies, the snowballing helped discover another 17 studies. We believe we have included herein studies that represent the VBSE research population given the multi-phases search and that we employed inclusion criteria referring to the definition of VBSE. In order to validate the coverage of electronic search process, we manually checked whether the primary

studies we already knew about were retrievable from the online databases and we managed to retrieve the studies from the expected databases. All the databases employed only included fully-refereed papers; in this way we mitigated the threat of grey literature. We used a tool – Parsifal, to support most part of the study selection. This tool automatically manages duplicates, and helps with documenting the reasons for including/excluding a study.

There were numerous joint meetings to discuss the papers being screened, and the participation of the second author, who was the one with more experience in VBSE, in meetings and also the screening of titles and abstracts. This was done in order to minimize threats related to interpretive validity. Inaccuracy in data extraction and classification of studies were minimized when two researchers independently extract the data and the results were reviewed during a joint meeting. Throughout the mapping study process, several meetings (at least 8) were held and attended by the authors to discuss issues related to study selection, data extraction and classification. Each joint meeting lasts between one to four hours. In one of the joint meetings, we went through the full text of 60 studies in order to validate our selection. Any discrepancies were discussed and resolved during the joint meeting. All the authors carried out searches, and the selection of studies was checked by at least one other author, so to minimize possible biases, such as less familiarity with the VBSE research area.

5.3.3. Threats to validity relating to data

A possible threat relates to the extraction of data from all 143 primary studies, which was done by the first and the third author for all RQs, except for RQ2. However, the data extraction form and also a sample extraction were discussed in joints meetings between the first three authors, so to ensure that any possible ambiguities were solved. Some of the papers that were included were known to the second author; therefore this was also used as an additional safeguard to validate a sample of the data extracted. As for the data extracted to answer RQ2, this was done solely by the second author, who is an experienced and seasoned researcher in empirical software engineering. Furthermore, the classification used to measure their quality was chosen exactly because of its clarity. This was important so to minimise any subjectivity while extracting the data.

5.3.4. Threats to validity relating to research

Here there are two main validity threats. The first one relates to the experience of the authors. The second and fifth authors are very experienced researchers in empirical software engineering; the fifth author was the leading author in papers [15, 23], which are guidelines for conducting mapping studies in software engineering. The first author is also an experienced researcher in empirical software engineering. This mapping study also had a detailed protocol, which was followed rigorously. Furthermore, all the decisions were always discussed amongst the team, so enhancing the validity of the process that was undertaken. With regard to research generalisability, this mapping study's results are based on a sample of studies written in English, which were retrieved using a complex but wide search string. We screened through more than six thousand titles and abstracts, thus we believe that the results we present here are generalisable to the population of VBSE studies published in English.

6. Conclusions

This paper reviews VBSE studies published since 2003 with the aim to support SE community including researchers and practitioners through a collection and systematic classification of VBSE studies. We extracted value definitions and quality of studies (quality, rigour, credibility, and reporting). We classified the primary studies according to the VBSE agenda's principles and practices, research topic, research method, research type, contribution facet, and the publication venue. In this review we included 143 studies that fulfill our selection criteria and relevant to answer the research questions.

Our results showed that the term "value" has not been clearly defined in many VBSE studies, but most studies have cited either the seminal paper by [1] or the VBSE edited book [2]. In terms of quality of studies, most studies have presented very good qualiy of reporting and relevance; however, the results for studies' rigour were mixed, with the largest number of studies presenting poor rigour, followed by very good and unsatisfactory rigour. Finally, credibility was assessed as acceptable for most studies, followed by good.

The results showed that VB Requirements Engineering (37 studies, 26%) and VB Planning and Control (25 studies, 16%) were the two principles and practices mostly researched in VBSE literature, whereas VB Risk Management, VB People Management, and Other were the least researched (3% respectively). Studies in VB Requirements Engineering mostly focused on proposing new methods, processes and techniques for prioritizing requirements and mechanisms to elicit and reconcile stakeholder's value propositions.

When classified according to the SWEBOK Knowledge Area, we identified that many VBSE studies fall under the Software Requirements (34 studies, 24%) and the SE Management (30 studies, 21%) areas. In terms of research methods used by the included studies, 55 studies (38%) used case-study methodology, hence it appears to be the most common method employed. Other methods used were surveys, experiments, action research, prototyping, literature review, quantitative analysis, simulation, and mixed methods. A total of 12 studies (8%) did not declare findings, and 23 studies (16%) did not report empirical findings. While research conducted in industrial and organizational context commonly applied case study, mixed-method, and survey methodology, formal experiments are mostly conducted in academic setting

There are a small number of evaluation studies available in the VBSE literature (20 studies, 14%), and many studies either presented solution proposal (42 studies, 29%), or solution together with the validation (39 studies, 27%). Research methods used for empirical evaluation studies are mainly survey and case study. In relation to the contribution facets, most contributions were provided as methods (32 studies, 22%) and processes (31 studies, 22%), while there were very few studies that proposed metrics and tools (2 studies, 1%).

Most studies (88 studies, 61%) were conference papers presented in 57 different conference venues where ESEM, EUROMICRO SEAA, EDSER, SEKE and PROFES provided the highest number of VBSE papers. The remaining studies comprised journal papers (37 studies, 26%) and book chapters (18 studies, 13%). As part of our future work we seek to investigate how the value-based decision-making process could be influenced by the stakeholders' personality. This could potentially help address the lack of research in VB People Management in the effort to improving stakeholders' decision-making process.

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Appendix A. Primary studies

List of selected studies

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Appendix B. Value definitions

Value definition(s)	Study ID	Reference(s) used
Value is defined at broader level as: "relative worth, utility or criticality'' or "something intrinsically desirable.''	[S9]	[1]
Value is defined as "a belief that a specific mode of conduct or end-state is personally or socially preferable to its opposite. Values serve as criteria for judgment, preferences, choices, and decisions as they underlie the person's knowledge, beliefs, and attitudes". – p. 74	[S15]	[28]
"Value concerns important benefits of stakeholders, e.g., tangible or intangible, economic or social, monetary or utilitarian."	[S20]	–
"Value can be: profits (generated from products), strategic positioning in market share, utility, relative worth, reputation, customer loyalty, innovation technology, cost reduction, quality of life, or improved productivity." – p. 450	[S25]	[S126]
"Value includes product, process and resource attributes. Value attributes include: profits (generated from products), strategic positioning in market share, utility, relative worth, reputation, customer loyalty, innovation technology, cost reduction, quality of life, improved productivity." – p. 287	[S26]	–

Value is defined based on Theory of Value, i.e., value refers to economic worth of goods and services, and that the value of entities can be seen in different perspectives, e.g., from intrinsic, subjective, or objective angle. Stakeholders have their value propositions and the value can be viewed from different perspectives in different dimensions (e.g., economics, organizational, technical, personal.)	[S38]	[S48], [S86]
"Value is defined as the net worth, or the difference between the benefits and the costs of the asset, all adjusted appropriately for risk, at a given point in time. When the costs are disregarded, implicit, or have been incurred before the point at which an asset is evaluated then value may refer to future benefits or the remaining worth of the asset at that point." – p. 42	[S47]	–
"Value" as "relative worth, utility, or importance." – p. 7	[S49]	–
"The economic concept of value is most commonly defined as the amount of money that a unit of goods or services is traded for. Utility, on the other hand, is all the good and desirable that is created by consuming a product or a service. Hence **the concept of value in VBSE is closer to economic utility than economic value**. To avoid confusion with the terminology, we use the term 'value' for value in VBSE context, and 'economic value' when discussing the economic concept." "In this paper we omit the philosophical definition of value and assume that value exists, and we can use any definition that suits our needs. Hence, we rather ambiguously define **value is the degree of desirability**."	[S77]	[49]
"Value is a measure – usually in currency, effort or exchange, or on a comparative scale – of software (set of programs, procedures, algorithms and its documentation) goods or services that will meet the user's needs, desires, and expectations. All goods or services are being influenced by the quality attributes of the software product." – p. 76	[S95]	[50] [S30]
Value is defined from 3 perspectives: product value (market value of the product, i.e., exchange value), **customer's perceived value** ("benefit derived from the product and is a measure of how much a customer is willing to pay for it, aka use value"), and **relationship value** (between company and customer).	[S101]	Economic theory (no reference)
Proposed definition of value: "The degree of fulfillment of stakeholder's requirements in order of their priority while maintaining the agreed upon commitments and constraints of quality."	[S110]	N/A

"Value depends on the relationship between customer needs and the benefits of products that satisfy those needs." "The value of a product for a customer is expressed in terms of benefit and cost, whereas to a software company it is expressed in terms of the profit (return) from the product sold."	[S126]	[1]
"Values are personal attitudes or long-term beliefs which may influence stakeholder functional and non-functional requirements."; "values may also be interpreted as a set of issues which are frequently referred to as problematic in the RE process, such as politics, culture, sensitivities about the consequences of automation and conflicts between stakeholders."	[S139]	[51]
"A wider view of value that exceeds its economic focus by including aspects such as 'relative worth, utility, or importance', and also presented the concept of key stakeholder to refer to all stakeholders who need to participate in the system definition and development processes."	[S143]	[1]

Appendix C. Detailed list of research topics

SWEBOK knowledge areas	Topics of investigation – Study ID
Software Requirements (34 studies)	Requirements analysis on market-driven software development – [S7]
	Requirements prioritization – [S8], [S13], [S14], [S19], [S24], [S28], [S30], [S35], [S55], [S60], [S65], [S72], [S116], [S119], [S137], [S140], [S142]
	Requirements elicitation – [S15], [S18], [S61], [S62]
	Tool support selection – [S21]
	Requirements tracing – [S86], [S92], [S130]
	Requirements selection decision-making criteria – [S97], [S107], [S126]
	Requirements negotiation – [S99], [S109]
	Value aspects of RE – [S101], [S104]
	Stakeholder identification and quantification – [S103]
SE Management (30 studies)	Software product innovation – [S3]
	Customer value – [S9], [S77]
	Planning and control – [S20], [S32], [S96], [S124]
	Stakeholders' value – [S43], [S108]

SE Management (30 studies)	Decision value/analysis – [S54], [S94], [S64], [S112], [S117], [S143]
	Software project management – [S4], [S25], [S38], [S68], [S136]
	Risks management – [S29], [S102], [S135]
	Product value estimation – [S79], [S95], [S110], [S34]
	Feature usage – [S84], [S88]
	Software value analysis – [S90]
SE Economics (17 studies)	VBSE Agenda – [S1], [S49]
	Product lines – [S36]
	Software initiatives valuation – [S47]
	VBSE Elements – [S50]
	Decision making support system – [S51]
	Value-based monitoring and control (Earned value management system) – [S70], [S105], [S121]
	Return-on-investment model – [S23], [S111]
	Software assurance investment – [S22], [S75]
	Value creation in agile projects – [S115], [S127]
	Multi-dimensional cost analysis – [S134]
	Maintenance cost estimation – [S106]
SE Process (14 studies)	Software process tailoring – [S5], [S87], [S120]
	Software development process – [S11], [S118]
	Software process modeling – [S17]
	Software process improvement – [S27], [S44]
	Process framework – [S31], [S42], [S76]
	Software dependability – [S41]
	Customer value analysis – [S82], [S138]
Software Quality (13 studies)	Stakeholders' alignment – [S10], [S91]
	Software quality assurance – [S16], [S113], [S114], [S123], [S125]
	Software quality processes – [S53], [S57], [S74]
	Verification and validation – [S71], [S73], [S100]
Software Design (11 studies)	Software architecture evaluation – [S12], [S132], [S133]
	Design decision – [S58], [S66], [S80], [S85]
	Components negotiation and reuse – [S63], [S78], [S129]

	System architecture investment – [S89]
Software Testing (08 studies)	Coverage measurement – [S6]
	Usability evaluation – [S45]
	Test management – [S46]
	Testing method – [S56], [S93]
	Testing decision prioritization using machine learning – [S59]
	Testing planning and controlling – [S83]
	Testing prioritization strategy – [S98]
Engineering Foundations (05 studies)	Business value analysis – [S39], [S33]
	VBSE Theory – [S48], [S69]
	Software productivity metric – [S81]
SE Models and Methods (05 studies)	Machine learning in VBSE – [S26]
	Inconsistent stakeholder value proposition – [S37]
	Decision support system development – [S52], [S139]
	Big data value engineering – [S122]
SE Professional Practice (03 studies)	Educational games – [S67]
	Group process – [S2]
	Stakeholder values and conflicts – [S128]
Software Maintenance (02 studies)	Software maintenance impact analysis – [S40]
	Migration of legacy applications and data structures – [S131]
Software Construction (01 studies)	Reuse value assessment – [S141]

Appendix D. Bubble plots and chart

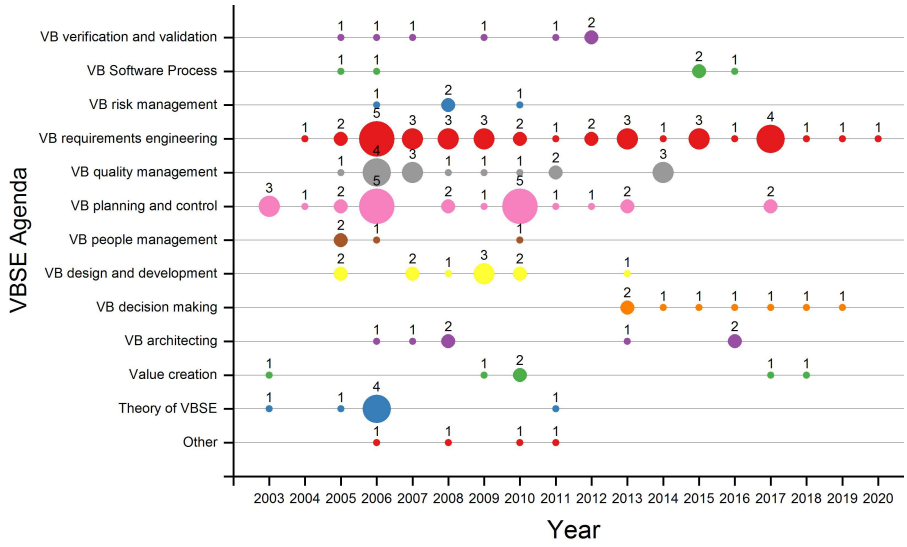

Figure D1. Bubble plot for VBSE principles and practices papers per year

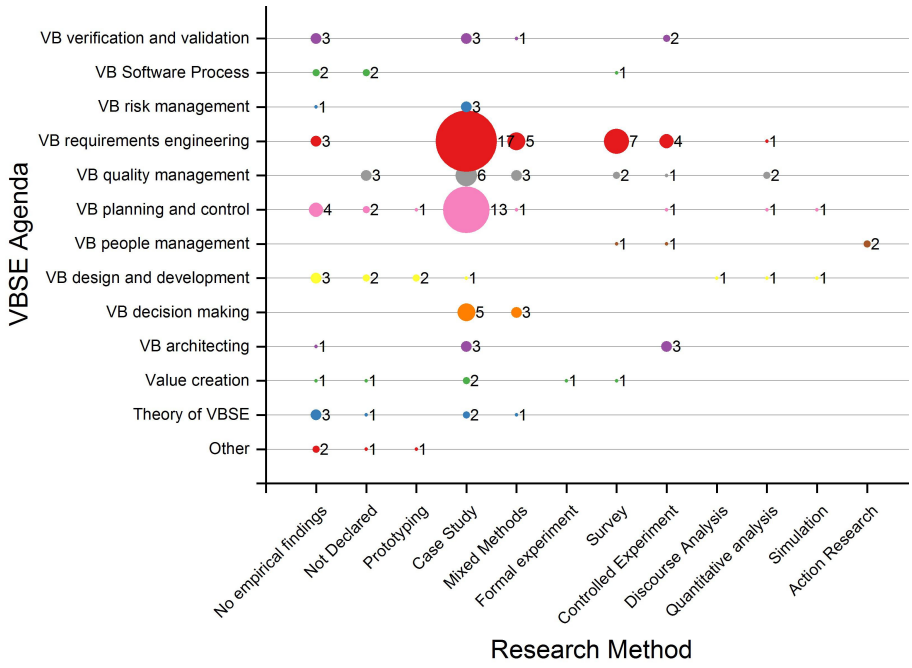

Figure D2. Bubble plot for VBSE agenda vs research method

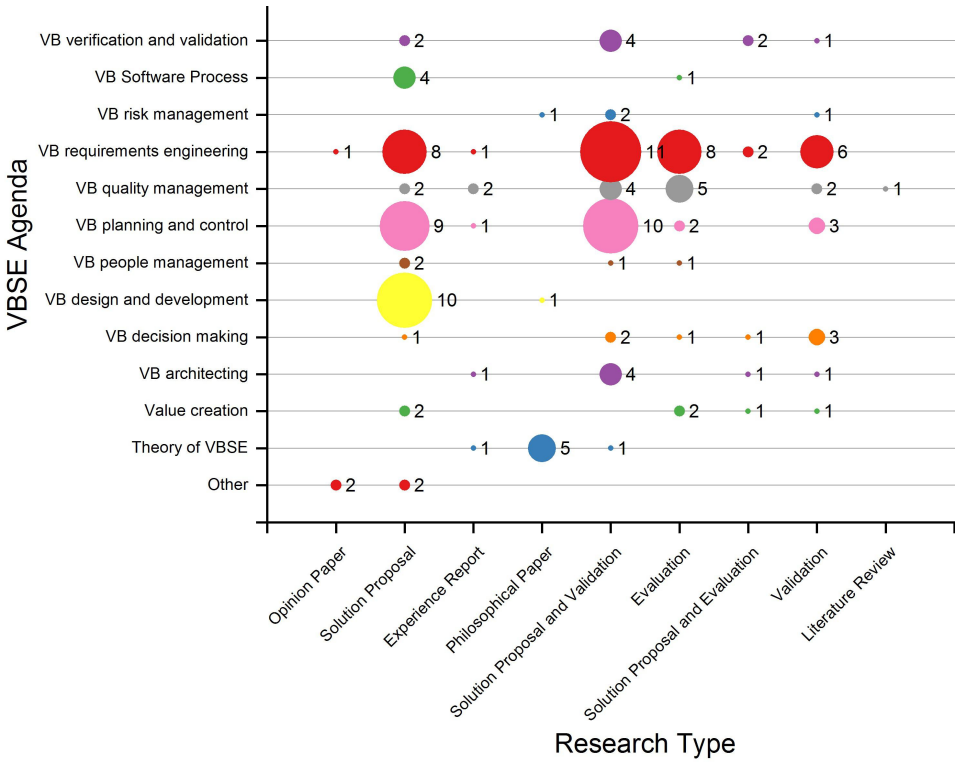

Figure D3. Bubble plot of VBSE agenda by research type

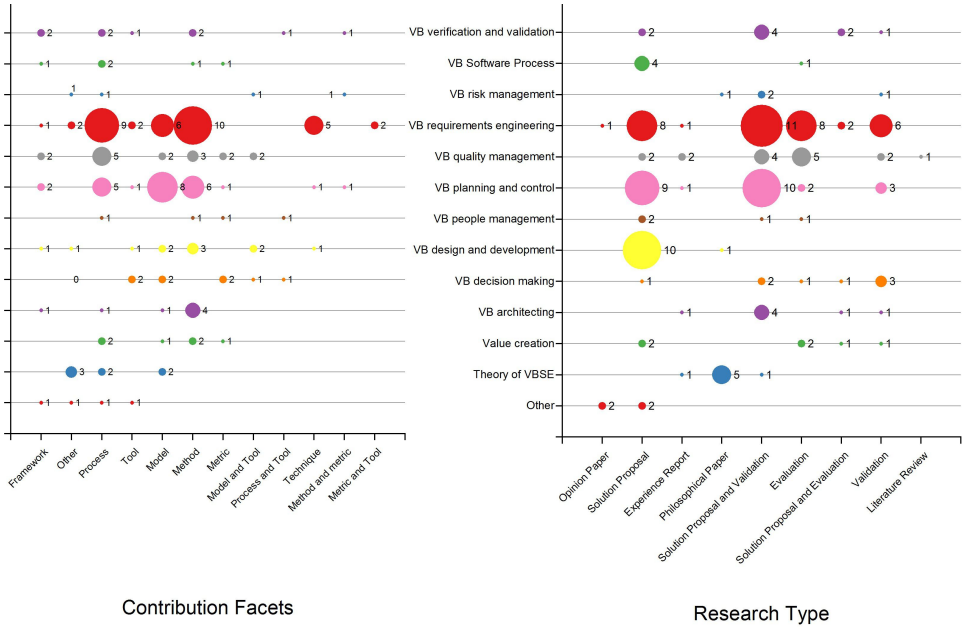

Figure D4. Bubble plot of VBSE agenda by contribution facets and research type

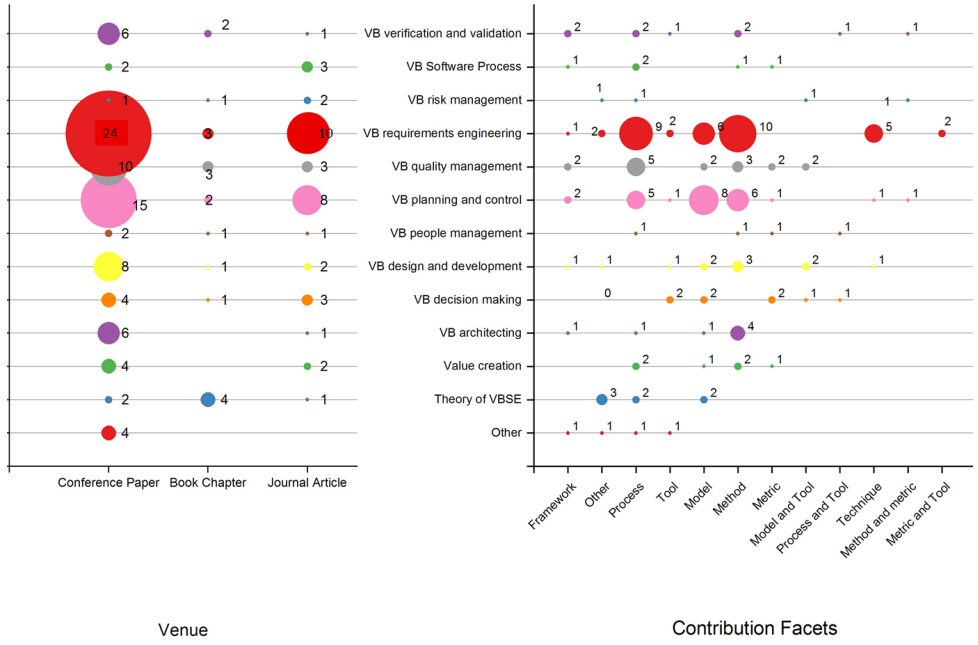

Figure D5. Bubble plot of VBSE areas by publication venue and contribution facets

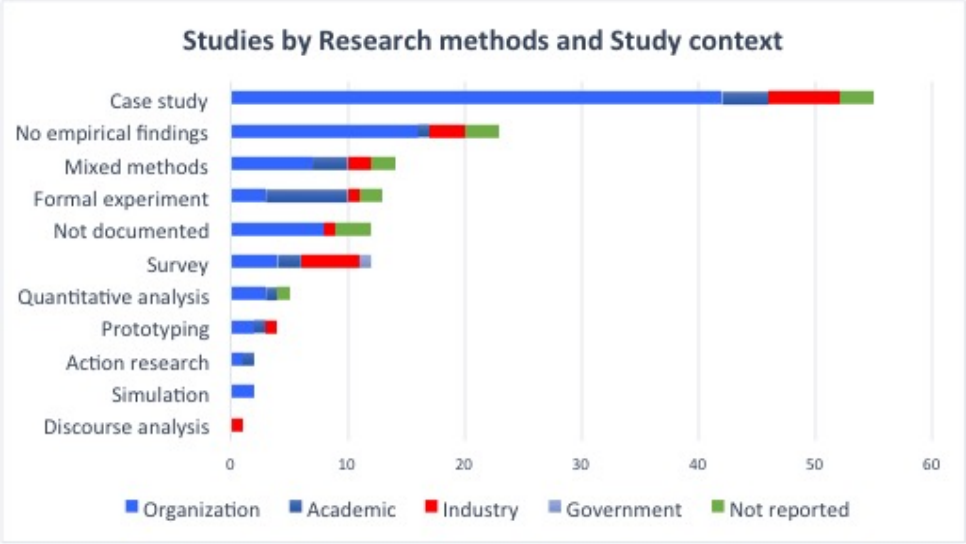

Figure D6. Bar chart on research method by study context

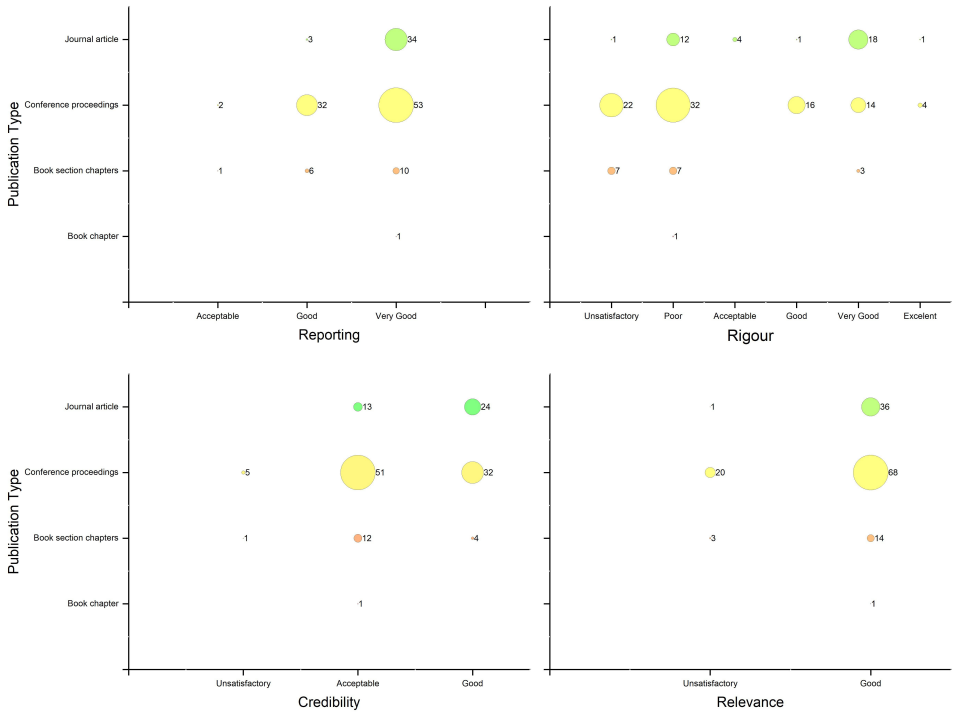

Figure D7. Bubble plot of studies' quality by publication type