When Rationality Meets Intuition: A Research Agenda for Software Design Decision Making

Replication Package

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Overview

This document contains the first part of the replication package for the paper titled *"When Rationality Meets Intuition: A Research Agenda for Software Design Decision Making"*.

This study has been designed, developed, and reported by the following investigators:

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The replication package comprises multiple files that are structured and accessible in both .xlsx and .csv formats. Their descriptions and links can be found below and on the Github page.

1. Protocol & Codification Framework - Document *Protocol & Codification Framework* - Describes search methodology and the parameters for coding, their descriptions and possible values.
2. Databases and results - Document *Databases* - Table with queried databases and results
3. Primary Studies - Document *PrimaryStudies* - Complete table of the 26 primary studies included in the research.
4. Data Extract - Documents *PrimaryStudiesDataCoded* and *PrimaryStudies-DataNonCoded* - Extracted data for all primary studies.
5. Rationale - Documents *Rationale* $<$ *parametername* $>$ - Full rationale and classification tables for each parameter.

Abstract: Context. As society's reliance on software systems escalates over time, so too does the cost of failure of these systems. Meanwhile, the complexity of software systems, as well as their design, is also ever-increasing, influenced by the proliferation of new tools and technologies to address societal needs. The traditional response to this complexity in software engineering and software architecture has been to apply rational approaches to software design, through methods and tools for capturing design rationale and software architecture knowledge management. However, research from other fields demonstrates that intuition may also hold benefits for making complex design decisions. All humans, including software designers, make use of both intuition and rationality in varying combinations.
Objective. The aim of this article is to provide a comprehensive overview of what is known and unknown from existing research regarding the use and performance consequences of using intuition and rationality in software design decision- making.
Methods. To this end, a systematic literature review has been conducted, with an initial sample of 3909 unique publications.
Results. We propose (1) an overview of existing research, based on the literature concerning intuition and rationality use in software design decision-making; and (2) a research agenda with fourteen future research questions, that should encourage researchers to fill identified research gaps. The research agenda and corresponding research questions were developed by means of a narrative synthesis, by reflecting on the research gaps based on findings concerning the use of intuition and rationality in decision-making from other domains. Conclusions. This research agenda emphasizes what should be investigated to be able to develop support for the application of the two cognitive processes in software design decision-making.

Keywords: software design, decision-making, intuition, rationality, systematic literature review, research agenda

Systematic Literature Review Methodology

This section presents the research protocol (i.e., how data were collected and analyzed). A systematic literature review approach was adopted because the study goal was to facilitate understanding by aggregating and organizing evidence into a classification. This section details the approach used, which is based on established guidelines (cf. Kitchenham et al. (2015); Wohlin (2014)).

Systematic Literature Review Protocol

The goal of this systematic literature review was to review, summarize and synthesize the current state of software design decision-making involving intuition and rationality, focusing on *when* intuition and/or rationality are used and *how* are they primed and used.

Search Strategy

To ensure that the search strategy adequately retrieved relevant literature while remaining feasible, the authors identified ten well-known, relevant studies based on a pilot study, as presented in Pretorius et al. (2018). The resulting pilot sample was used to refine the search strategy.

Search query

We utilized keywords and synonyms pertaining to *decision-making*, *design*, and *intuition and rationality* respectively to define our search query. In Table 1, three groups of keywords are shown in the respective columns. Group 1 includes search terms pertaining to decision-making behaviors. Along with the generic term "decision making", "choice" and "judg?ment" [1] were included to locate literature that refers to decision-making processes in terms of classical decision theory (Simon, 1955; Mintzberg et al., 1976; March, 1994; Tversky & Kahneman, 1974). Terms referring to specific decision-making behaviors such as "information gathering" and "trade-off" were also included. Group 2 includes software design as well as (product) development terms, since software design processes are often intertwined with (software or product) development activities (Budgen, 2003; Van Vliet & Tang, 2016; Zannier & Maurer, 2005). Further, requirements and planning keywords that may indicate the initial stages of design were also incorporated (Avison & Fitzgerald, 2002; IEEE, 2014). Finally, Group 3 comprises various synonyms and proxies for the initial keywords "intuition" and "rationality" (Dane & Pratt, 2007; Evans, 2008; Klein, 2015; Stanovich & West, 2000). The final search string was modified for each source database as the syntax for each varied.

Sources

The search query was run against the abstract, title, and keyword list. The developed search queries were subsequently run on six online databases — *ACM Digital Library, IEEE explore, ScienceDirect, SpringerLink, SCOPUS* and *Web of Science* as per (Dybå et al., 2007).

[1] The question mark symbol is used to denote the fact that a single character may or may not appear in its place, permitting both the terms "judgment" as well as "judgement"

Table 1: Search keywords for literature sample

Group 1	**Group 2**	**Group 3**
choice	information system analysis	analytic
decision analysis	information system design	associative
decision making	information system development	automatic
decision-making	information system planning	*conscious*
idea screening	information system requirements	dual-process*
information gathering	new product	experiential
judg?ment	product design	explicit
option analysis	product development	gut-feel*
trade-off	software architecture	heuristic
	software design	holistic
	software development	implicit
	software planning	intuit*
	software requirements	naturalistic
		rational
		reasoning
		reflect*
		reflex*
		system 1
		system 2
		tacit

Inclusion and Exclusion Criteria

We applied the following inclusion criteria:

- I1: Any English, published, peer-reviewed study that investigates issues related to intuition or rationality employed during the decision-making in software design.
- I2: The investigation of intuition and rationality must be the main focus of the study or a secondary issue that arises in a relevant manner.

The exclusion criteria are:

- E1: Studies where no software design issues are considered (rationale: focus area of the study).
- E2: Studies where no intuition or rationality addressed (rationale: focus area of the study).
- E3: Published in a language other than English (rationale: comprehension among authors).
- E4: Book or unpublished chapter (rationale: the aim is to gather and analyze particular studies).
- E5: Entire conference proceedings (rationale: the aim is to gather and analyze particular studies).
- E6: Retracted by author or publisher (rationale: scientific integrity).
- E7: Editorial or basic position paper (rationale: not peer-reviewed).
- E8: Unavailable in digital library or public domain (rationale: availability to authors).

Quality assessment

The remaining publications were subjected to a further quality check based on the SCImago Journal Rank (SJR) indicator to ensure that articles and papers were of sufficient quality. As the goal of the systematic literature review was to present an overview of the current literature in terms of what has been studied rather than draw specific conclusions, the quality checks advocated by Kitchenham et al. (2015) and Wohlin et al. (2012) were not applied.

Backward and forward snowballing

Backward and forward snowballing was iteratively applied (Wohlin, 2014) to locate publications that cited or were cited by the root publication. The suggestion provided by Wohlin et al. (2020) for using the SCOPUS database for backward and forward snowballing was adopted. We followed two iterations of backward and forward snowballing until no new articles were found. This step led to 3 new studies.

Data Extraction and Analysis

To develop the codes, the authors followed the suggestion of Miles & Hubermann (1994), and an initial start-list of codes was created based on the theoretical underpinning presented below. To achieve consistency, coding was completed by two authors independently, and disagreements were resolved in consensus meetings among these two authors along with one of the other authors. The full list of parameters and codes can be found in Section

Based on the insights and concepts applied in other studies in behavioral software engineering and software design decision-making (Mendes et al., 2019; Razavian et al., 2019; Mohanani et al., 2018), the coding scheme distinguishes (1) *when*: the *stage of the software design process*, the *contextual factors* as well as the *performance outcomes*, and (2) *how*: *antecedents* inducing use of intuition and rationality, and *contextual factors* strengthening or weakening their effects. Hereafter, the theoretical underpinning of the categories of codes is described.

Intuition and rationality. Table 5. The literature from related domains provides ample evidence to suggest that the use of either intuition or rationality or a combination of both, could also be beneficial for software design decision-making (cf. Hodgkinson & Sadler-Smith (2018); Dijksterhuis & van Olden (2006)). In the coding scheme, the study therefore distinguishes between use of intuition, rationality or a combination of the two in design decision-making in general, and in particular, software design stages.

Software design stages. Table 8. This study distinguishes three stages of software design (1) *design planning*, (2) *problem space*, and (3) *solution space*.

Individual and team. Table 10. The coding scheme also incorporates the *individual* decision maker and the *team* (or group) decision-making level, to cover different units of analysis (Lenberg et al., 2015) and to create a better understanding of group dynamics and consensus building in teams (Tofan et al., 2014) and especially the role of intuition and rationality in this regard.

Performance outcomes. Table 9. Combining existing theories from software (design) decision-making (Mendes et al., 2019; Razavian et al., 2019) with theories on decision-making from the closely related domain of new product development, the coding scheme distinguishes three types of design decision-making performance outcomes at two levels of analysis (Krishnan & Ulrich, 2001; Tatikonda & Montoya-Weiss, 2001). Two of the performance outcomes focus on the outcomes of single design decisions being made, i.e. (1) the *decision-making process performance* of a single design decision, such as decision-making efficiency (Mendes et al., 2019; Razavian et al., 2019), and (2) the *decision-making outcome* of a single design decision, for example, decision quality or decision error (Mendes et al., 2019; Razavian et al., 2019). The third performance outcome focuses on the software project level, i.e. the (3) *project outcome*, such as the quality of the resulting design or software product (Razavian et al., 2019).

Situational factors. Tables 11&12 Two types of situational factors are distinguished to contextualize the use of intuition and rationality in software design decision-making, to create a better understanding for *when* the use of either approach is beneficial or detrimental (contextual factors) as well as *how* one can prime each (antecedents) (Razavian et al., 2019; Dybå et al., 2012). Both contextual factors and antecedents can be categorized using characteristics suggested by Clarke & O'Connor (2012): i.e. the characteristics of (1) the *personnel* involved in the project, such as experience, (2) the *software requirements*, such as feasibility, (3) the *software application* itself, such as its relative size, (4) the *technology* utilized, such as emerging technologies, (5) the *organization*, such as available facilities, (6) *operational considerations*, such as the end users, (7) *management* overseeing the software development team, such as management expertise, (8) and *business considerations*, such as time-to-market.

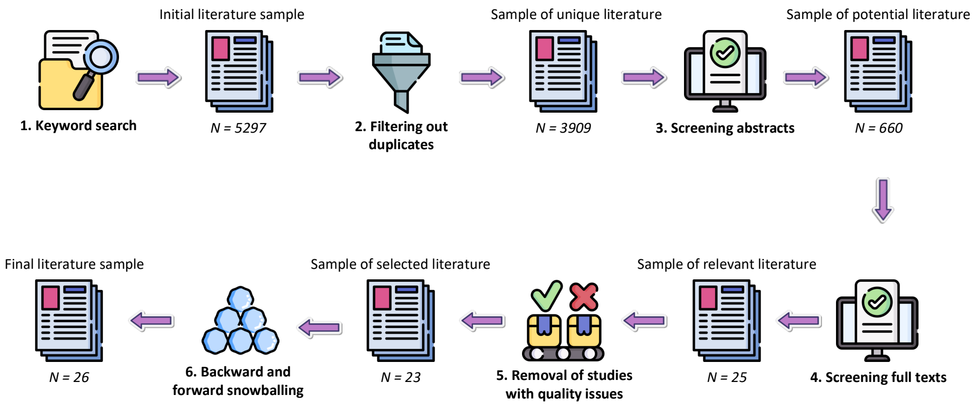

Figure 1: Overall literature search strategy

Conducting the Systematic Literature Review

Figure 1 shows the overview of the research process. The search was carried out with coverage until end-August 2021[2], and resulted in 5297 articles (Step 1). A combination of the automatic duplicate removal procedure present in *JabRef* and manual removal was used to locate and remove exact duplicates (Step 2). A total of 1388 duplicates were removed during these processes, leaving 3909 unique studies. Next, the articles were screened by means of inclusion and exclusion criteria, based on abstracts (Step 3), followed by full text (Step 4) only when necessary to reach a confident judgment. The first and second authors applied the inclusion and exclusion criteria. To improve rigor, this process was checked by two of the other two authors, who applied the inclusion and exclusion criteria to 50 randomly selected papers. Disagreements were resolved by consensus and discussion among the three authors, and inclusion and exclusion criteria were revised accordingly. Screening reduced the potential sample size to 660 studies based on abstracts, and thereafter, 25 studies based on full texts. Through quality assessment, two studies were removed from the sample at this point as they appeared in non-indexed publications (Step 5). We followed two iterations of backward and forward snowballing until no new articles were found (Step 6). This step led to 3 new studies. The final literature sample following the entire search and screening process totaled 26 studies, listed in the replication package document.

[2]The first iteration of this study was carried out in 2017 but was updated in 2021 to incorporate recent literature.

Codification Framework

This chapter defines the parameters of the codification framework related to the literature study. It first gives descriptions of parameters found in all Replication Package documents, after which all possible values of each parameter are listed.

Primary Studies Metadata

The Primary studies are described in Document *"PrimaryStudies"*. Their parameters are described in Table 2.

Table 2: Parameters for primary studies.

Parameter Name	Type	Description
Study Code	*Int*	Unique study identifier given to each primary study identification
Link	*String*	Link to main publication page of the study
Title	*String*	Title of the study
Author	*String*	List of all authors of the study
Year	*String*	Year of publication of the study
Venue	*String*	Venue in which the study was published
Study keywords	*String*	Keywords of the study as published on main publication page
Rationale for Field	*String*	Describes the focus of the study in relation to the field

Data Extraction Parameters

Extracted parameter data from the literature study for all primary studies is described in Table 3 and Table 4. Extra tables are provided in Section giving each parameters' full set of the possible coding values. The data extracted from the primary studies can be found in Documents *"PrimaryStudies-DataCoded"* and *"PrimaryStudiesDataNonCoded"*. The full rationale per parameter can be found in accompanying Documents *"Rationale $<$ parametername $>$"*.

Table 3: Parameters for Intuition and Rationality Clusters.

Parameter Name	**Type**	**Description**
Attributes of Intuition and Rationality	*Set*, see Tables 6 and 7	Conceptualizations of Intuition and Rationality
Intuition Cluster	*Set*, see Table 5 or 6	Attributes of intuition addressed in the study
Rationality Cluster	*Set*, see Table 5 or 7	Attributes of rationality addressed in the study
Element Classification	*Set*, see Table 5	Final classification of the study

Table 4: Parameters for Decision types, Performance category, Level of Analysis, Antecedents and Contextual Factors

Parameter Name	**Type**	**Description**
Decision Types	*Set*, see Table 8	Identification of stages of software design
Performance Category	*Set*, see Table 9	Types of design decision making performance outcomes
Level of Analysis	*Set*, see Table 10	Individual or team focus of the study
Antecedents	*Set*, see Table 11	Factors inducing the use of intuition and rationality
Contextual Factors	*Set*, see Table 12	Factors for when the use of either approach is beneficial or detrimental

Parameter Values

Possible parameter values for Intuition and Rationality Clusters and Classification in Table 3 are presented in Table 5.

Table 5: Possible codes for Intuition and Rationality from Evans (2008)

Category	**Cluster**	**Code**	**Description**
Intuition		**INT**	Gut-feeling about a decision option or matching scenarios with past ones
	Consciousness	**I-CON**	Speed and spontaneity of intuition as defining factors
	Evolution	**I-EVO**	Intuition in terms of the personal experience of the software designer
	Functional characteristics	**I-FUNC**	The associative or heuristic nature of intuition
	Individual differences	**I-IND**	
Rationality		**RAT**	Evaluating options using rules and logic
	Consciousness	**R-CON**	Explicit and controlled nature of rationality
	Evolution	**R-EVO**	Rationality in terms of its reliance on language
	Functional characteristics	**R-FUNC**	Rule-based, logical, and sequential nature of rationality is emphasized
	Individual differences	**R-IND**	

Attribute parameter values for Intuition are given in Table 6 and for Rationality in Table 7 on the next pages.

Table 6: Possible attribute values for Intuition parameter from Evans (2008)

Cluster	Attribute	Code	Description
Consciousness		**I-CON**	Speed and spontaneity of intuition as defining factors
	Unconscious (preconscious)	**UNC**	Non-awareness and compulsion
	Implicit	**IMP**	Non-awareness
	Automatic	**AUT**	Compulsive
	Low effort	**LEFF**	Requires low cognitive effort
	Rapid	**RAP**	Use takes a shorter time
	High capacity	**HICA**	Not constrained by requiring access to working memory
	Default process	**DFP**	Habitual response
	Holistic	**HOL**	Attending to entire field of information, using few categories or formal logic to reach understanding
Evolution		**I-EVO**	Intuition in terms of the personal experience of the software designer
	Evolutionarily old	**EOL**	Evolved in humans biologically prior to rationality
	Evolutionary rationality	**ERA**	Experiential
	Shared with animals	**ANI**	Lower-order
	Non-verbal	**NOV**	Is not reliant on language
	Modular cognition	**MOD**	Cognition consists of modules that correspond with a particular task
Functional characteristics		**I-FUNC**	The associative or heuristic nature of intuition
	Associative	**ASO**	The use of temporal and similarity relations to draw inferences and make predictions
	Domain specific	**DOS**	Relies on specialized knowledge
	Contextualized	**CTX**	Embedded in a context
	Pragmatic	**PRA**	Influenced by knowledge and context
	Parallel	**PAR**	Can perform many tasks at once
	Stereotypical	**STE**	Relies on heuristics and stored representations
Individual differences		**I-IND**	
	Universal	**UNI**	Available to all humans
	Independent of general intelligence	**IGI**	Not correlated with one's general intelligence
	Independent of working memory	**IWM**	Not correlated with one's working

Table 7: Possible attribute values for Rationality parameter from Evans (2008)

Cluster	Attribute	Code	Description
Consciousness		**R-CON**	Explicit and controlled nature of rationality
	Conscious	**CON**	Awareness and volition
	Explicit	**EXP**	Awareness
	Controlled	**CTR**	Of one's own volition
	High effort	**HIEFF**	Requires high cognitive effort
	Slow	**SLO**	Use takes a longer time
	Low capacity	**LOC**	Requires access to working memory system that can only hold a limited amount of sequential information at a time
	Inhibitory	**INH**	Suppression of habitual response
	Analytic	**ANA**	Paying attention to objects and their categories and using rules and formal logic to understand their behavior
Evolution		**R-EVO**	Rationality in terms of its reliance on language
	Evolutionarily recent	**EVR**	Evolved in humans biologically after intuition
	Individual rationality	**IND**	Based on self-knowledge and goals
	Uniquely human	**HUM**	Higher-order
	linked to language	**LANG**	Relies on language
	Fluid intelligence	**FLU**	Cognition is one consistent force, not broken down into modules
Functional characteristics		**R-FUNC**	Rule-based, logical, and sequential nature of rationality is emphasized
	Rule based	**RUL**	The use of symbolic structures that have logical content and variables; performing computations by means of rules
	Domain general	**DOM**	Relies on more general knowledge
	Abstract	**ABS**	Can be utilized without a context
	Logical	**LOG**	Influenced by rules of inference
	Sequential	**SEQ**	Can only perform one task at a time
	Egalitarian	**EGA**	Utilizing effortful reasoning on a moment-to-moment basis
Individual differences		**R-IND**	
	Heritable	**HER**	Not available to all humans, must be acquired
	Linked to general intelligence	**LIN**	Correlated with one's general intelligence
	Limited by working memory capacity	**LIM**	Correlated with one's working memory capacity

The parameters presented in Table 4 each have their own set of possible values.

Table 8: Possible parameter values for Decision Types

Category	**Name**	**Code**	**Description**
Performance	Design planning	**DP**	Decisions around scoping, and identifying key design issues
	Problem space	**PS**	Decisions linked to analysis of the design problem
	Solution space	**SS**	Decisions linked to the generation, evaluation, and selection of a design solution

Table 9: Possible parameter values for Performance

Category	**Name**	**Code**	**Description**
Performance	Decision outcome	**DO**	Outcome of a particular decision
	Decision making process	**DMP**	Evaluation of decision process itself
	Project outcome	**PO**	Outcome of the project as a whole

Table 10: Possible parameter values for Level of Analysis

Category	**Name**	**Code**	**Description**
Level of Analysis	Individual decision making	**IDM**	The presence of a single decision maker in decision
	Team decision making	TDM	Multiple decision makers involved in decision

Table 11: Possible parameter values for Antecedents from Clarke & O'Connor (2012)

Category	Name	Code	Description
Antecedents	**Application**	**A-APP**	Linked to the nature of the application being developed
	Business	**A-BUS**	Business and strategic considerations
	Management	**A-MAN**	Management involved in the software development project
	Operation	**A-OPR**	Considerations and constraints linked to operations
	Organization	**A-ORG**	Organizational issues pertinent to the software development project
	Personnel	**A-PER**	Personnel involved in the software development project
	Requirements	**A-REQ**	Requirements of the software being developed
	Technology	**A-TEC**	Technology used for the development project

Table 12: Possible parameter values for Contextual Factors from Clarke & O'Connor (2012)

Category	Name	Code	Description
Contextual Factors	**Application**	**C-APP**	Linked to the nature of the application being developed
	Business	**C-BUS**	Business and strategic considerations
	Management	**C-MAN**	Management involved in the software development project
	Operation	**C-OPR**	Considerations and constraints linked to operations
	Organisation	**C-ORG**	Organizational issues pertinent to the software development project
	Personnel	**C-PER**	Personnel involved in the software development project
	Requirements	**C-REQ**	Requirements of the software being developed
	Technology	**C-TEC**	Technology used for the development project

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