USABILITY-CENTRED SELECTION OF PROCESS MODELLING TOOLS IN HIGHER EDUCATION: A MULTIVOCAL LITERATURE REVIEW

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ABSTRACT

Business process modelling underpins improvement, communication, and educative clarity in tertiary education. Selecting a usable, context-fit tool, particularly among free-to-use options, remains challenging and requires a consolidated evidence base. The purpose of this article is to review existing literature, searching for decision-making guidance when a tertiary educator has to select the most appropriate process modelling tool.

The review confirmed a gap in comparative, usability-centred evaluations of free-to-use Business Process Modelling and Notation (BPMN) tools for tertiary contexts. A systematic search of peer-reviewed and grey literature, with backward and forward snowballing, was conducted. A class of problems was validated through thematic analysis of problem instance analysis, with proposed solutions, highlighting persistent selection needs for free-to-use tools and recurring usability challenges in education. Tools identified in the grey literature were compared, based on their features and against minimum requirements for tertiary use, with feature importance weighted. Existing methodologies, used for tool selection, inform a solution artefact design.

Evidence shows few tertiary-specific comparisons, inconsistent and poorly reported usability metrics, and gaps in coverage of features important for teaching and learning. The review includes tertiary-specific

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requirements, a structured feature list, and a preliminary prioritisation scheme for decision support.
Keywords: BPMN, process-modelling, usability, tool selection, decision support, tertiary education, systematic review, grey literature

1 INTRODUCTION AND RESEARCH OBJECTIVES

According to Lytvyn, et al. [1], innovation and effective implementation of digitalised business processes play an important role in enhancing a company's competitiveness. Over the past decade, digital technologies have proven to be powerful tools that can improve efficiency and drive rapid enterprise development. These technologies not only improve productivity but also develop both the internal and external environments of businesses, impacting their competitiveness in the market. Within this context, Business Process Model and Notation (BPMN) provides a language for the graphical representation of existing operations in both production and service environments [2].

1.1 Problem context

Education of enterprise designers at tertiary level requires practical experience with process modelling tools and clear understanding of tool limitations across different contexts of use [3]. Modelling objectives include analysis of existing processes prior to digitisation and analysis of implementation deficiencies after deployment. The selection of an appropriate process modelling tool depends on alignment between objectives, feature needs, and non-functional requirements. Usability functions as a central nonfunctional requirement and is defined as ease, efficiency, and satisfaction of use as a software quality attribute [4], and the ISO 9241 11 standard describes it as achievement of specified goals with effectiveness, efficiency, and satisfaction in a specified context of use. *Satisfaction* refers to user happiness with task completion, *effectiveness* refers to task completeness, and *efficiency* refers to effort required for task completion [5]. Emphasis on usability within the software selection for process modelling artefacts aims to reduce dissatisfaction and inefficiencies in a tertiary education setting.

1.2 Problem instance analysis

This literature review indicates the absence of a comparative study that integrates feature offerings and usability for free-to-use process modelling tools. An incumbent desktop tool, Bizagi Modeler 4.2, is used at a Tertiary Education Enterprise (TEE), with observed usability concerns that initiated a search for an alternative, aligned with two stakeholder groups, lecturers and students. The primary measure for validation concerns the usability of the tool, where qualitative evidence from structured experimentation provides the basis for diagnosis.

1.2.1 Data gathering using experimentation

Experimental work, done by the main researcher, applied the tool to complete a compulsory undergraduate BPMN exercise using official instructions and supporting material given to the students. The documentation used to proceed with experimentation is shown in Table 1. Observations recorded areas of concern, perceived causes, and candidate remedies to inform validation of the problem instance.

Table 1: Documentation used for experimentation

Title	Author	Year	Description
Enterprise Implementation using BPMN: Introduction	Lecturer A	2023	Class notes introducing undergraduate students to the BPMN process model
Designing a BPMN diagram with the transaction pattern in mind	Lecturer A	2023	BPMN exercise required in the designated undergraduate module
Designing a BPMN diagram with the transaction pattern in mind Memorandum	Lecturer A	2023	Memorandum for the BPMN exercise in the designated undergraduate module

1.2.2 Experimentation results

A baseline usability appraisal of the Bizagi Modeler used the assessed BPMN exercise with learning outcomes that included: (1) Differentiation between Design and Engineering Methodology for Organizations (DEMO) and BPMN models; (2) Understanding the relationships among previous process related models and BPMN; (3) Distinguishing between core BPMN diagram types; (4) Application of BPMN 2.0.2 elements and examples; and (5) Construction of a diagram that incorporates coordination acts of the basic, standard, or complete transaction pattern. Initial observations were organised according to effectiveness, efficiency, and satisfaction, summarised as follows:

- **Ease of use:** Interface density, discoverability of specific BPMN elements, intermittent responsiveness during the control of elements, and repeated validation prompts affected ease and learnability. Also, hover tooltips and embedded help resources supported learning.
- **Efficiency:** Quick linking and partial auto connection improved speed, but mandatory drag and drop placement, inconsistent alignment behaviour, and prompts shown during saving interrupted workflow.
- **Satisfaction:** High-quality rendering and completion of the exercise supported satisfaction, while lack of real-time collaboration, absence of a spell checker, and label layout constraints reduced perceived quality for teaching and co-modelling use.

An example of one of these cases, namely the auto connection issues from the experimentation can be found in Figure 1.

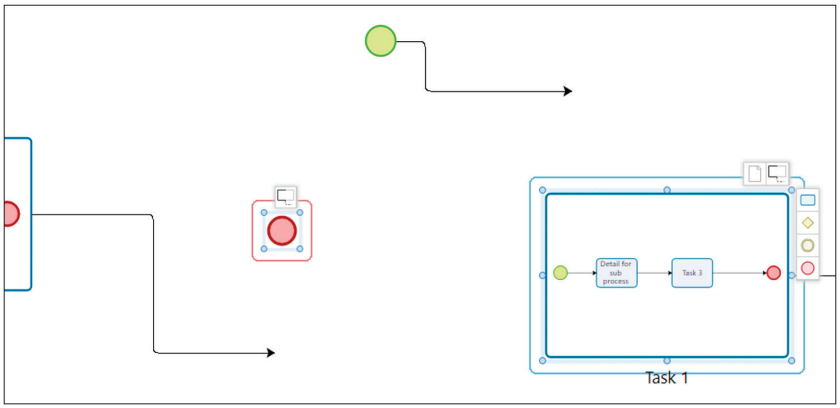

Figure 1: Sequence flow detachment observed when repositioning elements

These findings suggest that the Bizagi Modeller is generally usable within a tertiary context for students who receive adequate learning resources. However, its efficiency and ease-of-use limitations may present barriers to less experienced users. A summary of these findings is found in Table 2.

Table 2: Summary of experimentation observations

Framework	Observations
Ease	Mixed. Help resources aid learning. Interface appears cluttered. Several functions are difficult to locate or are unintuitive.
Efficiency	Moderate. Shortcuts enhance speed. Validation prompts and manual adjustments reduce workflow fluency.
Satisfaction	Generally positive. Task completion is achievable and rewarding. Minor frustrations detract from overall experience.

This study's stakeholders include lecturers responsible for teaching and assessment, and undergraduate students. Minimum entry requirements articulated by lecturers include BPMN 2.0 support, availability of a no-cost version, and rendering of high-quality images for document use. Preferred but non-mandatory requirements include participative modelling with a co-modeler and cloud-based access without operating system installation. A *fee-to-use* condition serves as an exclusion for possible tools in a tertiary education setting.

1.2.3 Problem statement

A comparative study on feature offerings and non-functional requirements affecting usability of free-to-use process modelling tools does not exist. Hence lecturers have to experiment with multiple process modelling tools prior to selecting the most suitable tool for their teaching context.

1.3 Research questions and structure

The study focuses on the explorative phase of a research study that includes the following discovery research questions:

DQ1: What are the problems experienced at an existing tertiary education enterprise regarding evaluation of an existing process modelling tool?

DQ2: What are the main concepts associated with process modelling, software tooling, and tool usability in a tertiary education setting?

DQ3: Does the presence of the problem instance feature as a *class of problems* in existing literature?

DQ4: What software selection solutions exist that address the *class of problems*, including existence of systematic literature reviews that compare free-to-use process modelling tools in a tertiary education setting, evidence of experimentation with software selection business process modelling tools in tertiary settings, and evidence of usability issues with business process modelling tools in other enterprises?

DQ5: What are the existing tools that comply with the free-to-use requirement of the tertiary education enterprise?

DQ6: What are the requirements of a solution that needs to be developed to address the *class of problems*?

The investigation addresses a documented gap concerning the comparative

study of feature offerings and usability of free-to-use process modelling tools. Bizagi Modeller 4.2 is used as the current tool within a department at a tertiary education enterprise. Observed usability problems initiated a search for an alternative that better aligns with the needs of students and lecturers in a tertiary setting. This article uses a multivocal literature review, which is a form of Systematic Literature Review (SLR) which includes grey literature (for example, blog posts and white papers) in addition to published (formal) literature [6], to address the discovery questions.

The article is structured as follows. Section 1 provides an introduction to the problem context, answering DQ1. Section 2 provides a research protocol for a multivocal literature review, linked to discovery questions DQ2 to DQ6. Section 3 reports on the extracted themes, validates the class of problems, and consolidates selection requirements. Section 4 discusses the requirements from the themes present, explains their importance, and maps them to usability areas that are problematic, according to literature. Lastly, section 5 concludes and recommends requirements for tool selection, showing how they resolve problems and discovery questions.

2 LITERATURE REVIEW PROTOCOL

This section defines the protocol for a literature review to answer discovery questions DQ2 to DQ6. The review follows the eight-step traditional systematic literature review approach described by Okoli and Schabram [7]. New knowledge areas are additionally surveyed through a grey literature review conducted in line with guidelines by Garousi et al. [6]. The standard protocol structure for systematic reviews in software engineering is applied. In line with Okoli and Schabram [7], the review is arranged into the multi-step procedure, and the subsections reflect those steps, referenced as variation points at the relevant stages.

2.1 Keywords and digital repositories

Discovery question DQ4 informs keyword construction. Sub questions under DQ4 guide two complementary search strings. *The first string* combines terms for systematic reviews and mappings with terms for

process modelling tools and software, comparison and decision making, higher education settings, and free-to-use or open-access licensing. *The second string* combines terms for usability and user experience, process modelling and BPMN, software selection and evaluation, free-to-use availability, comparison and decision procedures, and tertiary education. In these strings similar and closely related expressions for each theme are joined with the Boolean operator "OR", and the theme sets are joined with the Boolean operator "AND" to balance retrieval and precision while maintaining relevance to the study focus. The strict Boolean intersections increase precision but can lower results where licensing or education terms are absent, and restricted coverage may omit studies using alternative terminology.

Concepts related to usability in tertiary education (DQ2) were extracted from studies returned by both search strings. The initial academic search indicated limited evidence on process-modelling tool features. Therefore, a grey-literature review (GLR) was conducted to bridge these gaps by extracting from non-academic sources. The grey literature searches address DQ5 by focusing on software that satisfies requirements defined by the TEE in section 1.2.2.

Primary academic sources included SpringerLink, Scopus, and IEEE Xplore for comprehensive, high-quality coverage and authoritative peer-reviewed venues, combined with snowballing. Restriction to these databases provides reliable coverage of software engineering and information systems but may omit studies elsewhere that use alternative terminology, where backward and forward snowballing mitigated this constraint. Grey literature used a general web search engine to discover process modelling tools and supporting materials.

2.2 Snowballing procedure

Search efficiency is improved by combining database search with backward snowballing, followed by forward snowballing from the resultant set until saturation, as recommended by Wohlin et al. [8]. Backward snowballing identifies additional studies from reference lists of studies retrieved from Scopus and IEEE Xplore, where forward snowballing then identifies

studies that cite the selected set. The snowballing procedure followed is seen in Figure 2.

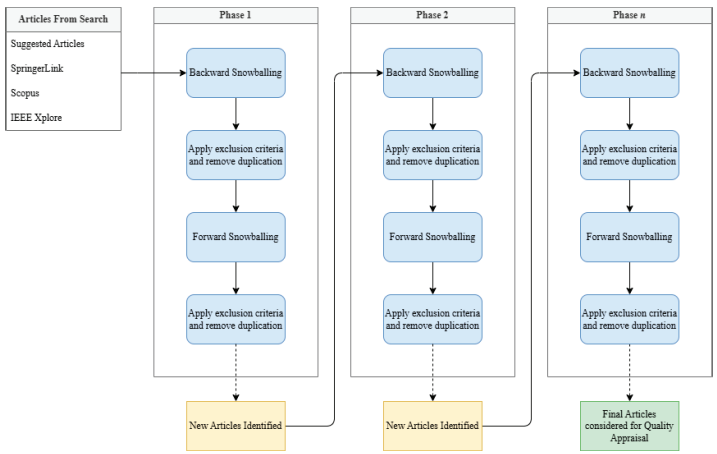

Figure 2: Snowballing procedure followed

2.3 Practical screening

Inclusion and exclusion criteria follow the guidelines provided by Okoli [9], with adaptation for the present topic. Titles and abstracts are screened first. Studies meeting exclusion criteria are removed with practical reasons recorded. The inclusion and exclusion criteria are included in Table 3.

Table 3: Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Content	Articles that emphasise or compare free-to-use process modelling tools. Articles that address usability needs of students and lecturers for process modelling tools. Any other studies relevant to the discovery questions.	Studies that predominantly discuss commercial tools unless a significant comparison or reference to free alternatives is present. Studies that focus on a single stakeholder group only or do not discuss usability. Studies that are not relevant to the topic.
Setting	Studies that discuss or evaluate software selection processes for business process modelling tools within tertiary education, with possible relaxation if the search proves too restrictive.	Studies focused on primary or secondary education.
Publication type	Peer-reviewed journals, conference papers, reputable books or book chapters.	Unpublished works, non-peer-reviewed sources, or unreliable publishers, with the exception that grey literature is considered *when identifying tools*.
Time frame	Studies published after public release of the BPMN specification in February 2006.	Studies outside the defined time frame.
Language and access	English language studies with full text availability.	Non-English studies or studies without full text access.

2.4 Quality appraisal

Peer-reviewed literature. Quality screening questions are adapted from the checklist by Kitchenham and Charters [10] for qualitative studies based on text or argumentation. The adaptation alters the questions to allow for a qualitative approach to answering the checklist by using the words, "to

what extent" instead of "how", including the following questions in Table 4.

Table 4: Quality appraisal questions for peer-reviewed literature

No.	Updated Appraisal Questions
1	To what extent is the level of credibility of the findings?
1.1	To what extent are the findings important within the context of the study?
2	To what extent has knowledge or understanding been extended by the research?
3	To what extent does the evaluation address its original aims and purpose?
4	To what extent is the scope for drawing wider inference explained?
5	To what extent is the basis of evaluative appraisal made clear?
6	To what extent is the research design defensible?
7	To what extent are the sample design and target selection of cases/documents well defined?
8	To what extent are the eventual sample composition and coverage described?
9	To what extent was data collection carried out rigorously and as intended?
10	To what extent has the approach to, and formulation of, analysis been clearly conveyed?
11	To what extent are the contexts and data sources retained and accurately portrayed?
12	To what extent has diversity of perspective and context been explored?
13	To what extent has detail, depth, and complexity (richness) of the data been conveyed?
14	To what extent are links between data, interpretation, and conclusions made explicit and traceable?
15	To what extent is the reporting clear and coherent?
16	To what extent are the assumptions, theoretical perspectives, and values shaping the evaluation made explicit?
17	To what extent is attention to ethical issues evidenced?
18	To what extent has the research process been adequately documented?

Grey literature. Assessment follows criteria adapted from Garousi et al. [6], that is, validating the authority of the producer, methodology, objectivity, date, novelty, impact, and outlet control.

2.5 Data extraction

From included academic studies, the following items were extracted using observations in section 1.2.2 and the usability dimensions defined by ISO 9241 11:

i. General details: author (year) and method type (Conceptual / Review / Empirical).
ii. Usability definition as stated, including named themes aligned to effectiveness, efficiency, satisfaction, learnability, and context of use.
iii. Concept evidence mapped to code families: Process modelling, software tooling, usability in tertiary context, teaching assessment, and barriers and enablers.
iv. Tertiary context: Stakeholder group and any module or assessment context.
v. Modelling practice: Purposes before digitisation and after implementation, and how different modelling approaches relate to each other (for example, BPMN and DEMO).
vi. Barriers and enablers: Interface density, BPMN element discoverability, alignment/snap grid behaviour, auto-connection behaviour, validation prompts on save, help resources, export quality, collaboration support, spell checking, label layout, and learnability notes.
vii. Concept presence flags (presence per concept) to help with analysis and graphing across studies.
viii. Problem statements on the selection or use of free-to-use process-modelling tools in tertiary education, or usability issues reported in enterprises or education.
ix. Consequences linked to the problem: Examples include reduced task completion, increased effort, reduced satisfaction, diminished teaching effectiveness, and impaired assessment clarity.
x. Proposed solutions, with the following examples: Alternative tool adoption, configuration/workflow adjustments, training/guidance, and documented evaluation and comparison practices.
xi. Indicator for problem-to-solution linkage where both appear in the study narrative.

From grey literature, candidate business process modelling tools, and all attributes necessary to address discovery questions in synthesis, were extracted.

2.6 Application of the protocol

2.6.1 Peer-reviewed literature

This section provides more detail on the execution of the protocol to validate that a class of problems exists and to extract existing solution areas.

Searching for literature: An initial broad search on SpringerLink, Scopus, and IEEE Xplore applied no filters to find existing Systematic Literature Reviews (SLRs) comparing business process modelling tools across domains: SpringerLink = 17 results; Scopus = 118 results; IEEE Xplore = 92 results. The search was then refined using the protocol search strategy to target SLRs that compare free-to-use BPM tools in a tertiary education setting. The outcomes per database are as shown:

- **SpringerLink:** Five results after refinement, but none were kept after exclusion criteria. One candidate SLR from the loose search remained relevant.
- **Scopus:** Seven results were displayed but none were relevant. The scope was widened to SLRs on BPM tools outside a tertiary education setting; four SLRs were retained after relevance screening.
- **IEEE Xplore:** Four results were displayed with only one being relevant. The scope was then widened and three additional relevant SLRs were identified, one already captured via another database.

Final SLR inclusions after strategy application and exclusion criteria were as follows: SpringerLink = 1; Scopus = 4; IEEE Xplore = 3. The total SLRs included = 8.

This showed that the database search confirmed the absence of SLRs that specifically compare free-to-use process modelling tools within

a tertiary education setting. However, broader SLRs offered useful comparative methods, evaluation frameworks, and tool-focused findings for synthesis. The search was then extended with the second protocol string to capture studies on process modelling, software tooling, and usability. The tertiary education criterion was relaxed to ensure adequate coverage while maintaining alignment with study objectives.

Practical screening: Titles and abstracts retrieved from SpringerLink, Scopus, and IEEE Xplore were screened against protocol inclusion and exclusion criteria. Restricting the search to free-to-use tools within a tertiary education setting proved too narrow and therefore constraints were relaxed as specified in the protocol. After applying the protocol search strategy, 649 articles were found across the three databases. Titles, abstracts, and full texts were then assessed for relevance as specified. This can be seen in Table 5.

Table 5: Practical screening of database search

Searching steps	SpringerLink	Scopus	IEEE Xplore
1. Loosely use the search string without many restrictions.	N = 3832	N = 1098	N = 391
2. Apply search strategy according to the protocol for keywords.	N = 431 Education and free-to-use restraints included	N = 183	N = 35
3. Apply exclusion / inclusion criteria	N = 207	N = 83	N = 20
4. Scan the titles manually for relevance.	N = 10	N = 16	N = 12 Low strictness applied
5. Scan the abstracts manually for relevance.	N = 5	N = 10	N = 4

From database searching, an initial set of 19 articles were retained (SpringerLink = 5; Scopus = 10; IEEE Xplore = 4). Three additional articles recommended by the lecturer were added for snowballing.

Snowballing: Backward and forward snowballing proceeded in two phases with predefined exclusion criteria applied at each stage. Phase 1 yielded 20 additional articles and Phase 2 yielded seven additional articles. A declining title and abstract relevance in Phase 2 indicated saturation, so snowballing concluded. As a result of this process, the total studies considered for the study was 50.

Quality appraisal: Quality appraisal followed the checklist as specified in the protocol. Each study received a score per item using 1 (fully met), 0.5 (partially met), or 0 (not met). Item scores were then summed, divided by the maximum possible, and expressed as a percentage. Inclusion required more than 60 percent, and applying this threshold then excluded five studies, leaving 45 studies for synthesis.

2.6.2 Identifying existing tooling in grey literature

Searching for literature: The search started by finding topics which provided considerations for identifying and selecting existing business process modelling tools. These discussions, summarised in Table 6, helped identify potential modelling tools that are considered at other stages.

Table 6: Knowledge areas relating to the selection of business process modelling tools

No.	Literature Type	Author	Title
1	Blog	Biskic [11]	How To Choose The Right BPM Tool with ADONIS
2	Blog	Mordy [12]	9 Best Free and Open Source Business Process Management Software
3	Blog	Jepma [13]	12 of the Top-Rated Free and Open-Source BPM Software Solutions
4	Blog	Zbigniew [14]	Free BPMN modelling tools – 2020 edition
5	Web Page	Wikipedia [15]	Comparison of Business Process Model and Notation modeling tools
6	Web Page	G2.com [16]	Business Software and Service Reviews

Practical screening: No sources were excluded for the grey literature review using the inclusion/exclusion criteria.

Quality appraisal: The appraisal technique is applied to the grey literature sources from one to six in Table 6. The scores from the appraisal questions equal a total of 20, where a threshold of 10 is used for this study, which means that the sources may be considered relevant if they conform to at least half of the questions from the checklist. All the sources conformed to at least half of the appraisal questions, and, therefore, none were excluded from the review.

2.7 Data synthesis plan

Extraction of main concepts (answers DQ2). Concepts related to process modelling, software tooling, and usability in tertiary education are derived through qualitative coding. A bubble plot visualises the frequency of concepts across studies.

Validation of a class of problems (answers DQ3 and DQ4). Thematic analysis as described by Guest et al. [17], is applied to studies that describe problem instances and proposed solutions. Evidence is assembled regarding the presence of a class of problems concerning the selection or use of free-to-use process modelling tools in tertiary education, and regarding usability challenges reported in other enterprises.

Identification of existing solution areas and tools (answers DQ5 and DQ6). Tools identified in the grey literature are analysed using feature-based comparison aligned with the minimum requirements defined in section 1.2.2. Feature importance is weighted by relevance to the TEE and supporting evidence in the literature.

3 PROBLEM CONTEXT RESULTS

The results provided here represent the findings from peer-reviewed and grey literature, according to the predefined protocol. Using the defined extraction items, main concepts are extracted and tallied, classes of problems are validated and existing tools with requirement alignment for tertiary education are identified. It should be noted that screening and extraction were performed by a single researcher using a fixed codebook and

documented criteria. No intercoder agreement was calculated; therefore, a risk of selection and coding bias remains. On the other hand, synonym expansion, documented inclusion and exclusion criteria, and backward and forward snowballing improved recall and transparency. Findings should be interpreted as evidence of presence rather than complete coverage, with residual selection and coding bias acknowledged.

3.1 Peer-Reviewed Literature

3.1.1 Main concepts

Concepts related to process modelling, software tooling, and usability in tertiary education were derived through qualitative coding extractions from the studies, where a bubble plot of these concepts over time can be seen in Figure 3.

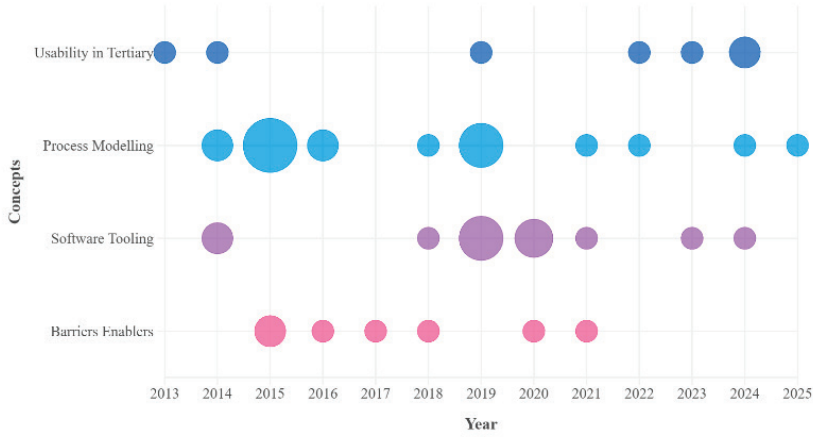

Figure 3: Rise of concepts over time

The extractions were then grouped under a common set of non-functional themes: Effectiveness, Efficiency, Satisfaction, Learnability, and Context of use. Additional items were recorded when present in the literature (such as Operability, Help resources, Collaboration support).

Dominant co-occurrences among themes

The most frequent pairs are Effectiveness/Efficiency and Efficiency/Satisfaction (each present in 20 studies). The most frequent triple is Effectiveness / Efficiency / Satisfaction (present in 18 studies). This pattern links outcome (Effectiveness) and experience (Satisfaction) with the effort and time it required (Efficiency), indicating that authors tend to link outcome and experience with the effort it required to get to that point.

Theme coverage at study level

Across the 45 studies, 22 have more than three themes, 23 have more than two themes, and five have exactly one theme each. This signals an integrative approach in which several usability-related themes are evaluated together within the same study, not treated as stand-alone attributes.

Presence of themes

To compare the relative salience of usability dimensions over time, themes were analysed individually and then summarised at study level. Efficiency appears in 25 studies, Effectiveness and Satisfaction in 20 each, Learnability in 14, and Context of use in 11. Additional themes appear less frequently: Operability (5), Help resources (2), and Collaboration support (1). These counts are presence tallies only and do not imply weighting beyond presence. A bubble plot was created with Year on the x-axis, the grouped themes on the y-axis, and bubble size equal to the number of studies that include the theme in that year. This plot is seen in Figure 4.

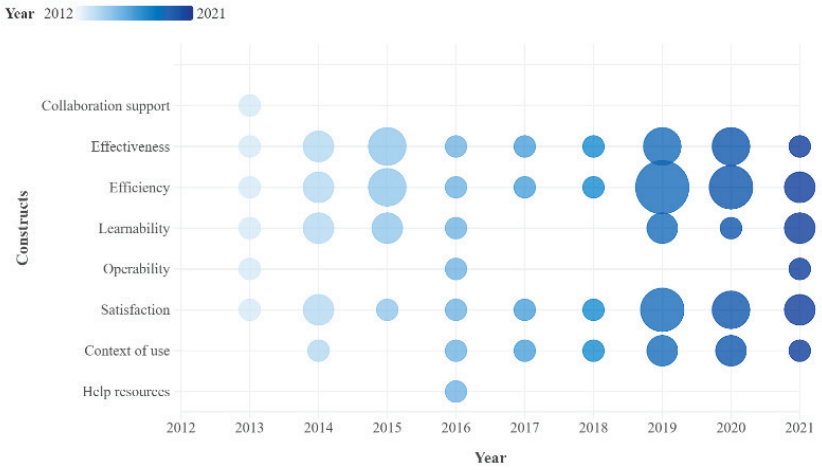

Figure 4: Rise of themes over time

It is seen that Efficiency is the most common theme overall (included in 25 studies), first appearing in 2013 and peaking in 2019. Effectiveness (included in 20 studies) and Satisfaction (included in 20 studies) are equally important, each first appearing in 2013, peaking in 2019. Learnability (included in 14 studies) first appeared in 2013, with a peak in 2014. Lastly, Context of use (Included in 11 studies) has been present since 2013, with a peak in 2019.

3.1.2 Validating a class of problems

Across 45 included studies, 16 explicitly paired a problem statement with a proposed solution, while 29 did not. This confirmed that some studies both described a problem instance and proposed solution within the same study. Problem statements were then mapped to categories based on the experimentation categories defined in section 1.2.2 (Ease of use, Efficiency, Satisfaction). A predefined list of keywords was developed for each category and used to analyse the problem statements, allowing studies to be assigned to one or more categories, as shown in Table 7.

Table 7: Findings about problem categories

Tooling Problem Categories	Findings
Operability and Manipulation	The most frequent category, which included difficulty with selection or movement of elements, disconnection of sequence flow during move operations, and unintuitive deletion or collapsing of sub-processes.
Workflow Interruptions and Validation	A frequent category, which included validation prompts on save and error message interruptions that broke the modelling flow.
Layout and Alignment	A frequent category, which included inconsistent snap-to-grid and alignment issues, label placement, and swimlane alignment concerns.
Learnability and Discoverability	A recurring category, which included difficulty discovering BPMN elements or their types, first-time use barriers, and reliance on tooltips or tutorials.
Interface Density and Clarity	A recurring category, which included dense or cluttered UI that hindered quick orientation.
Export and Documentation Quality	This was present but less frequent and concerned image quality for in-document use.
Collaboration and Co-modelling	This was present but less frequent and included lack of real-time co-modelling support.
Stability and Save Errors	This was present and referenced save errors or unstable behaviour.
Spell checking and Text Handling	This was present and referenced missing spell-check and label overlap.
Access and Authentication	Appeared occasionally and referenced login or connectivity prompts.
Assessment and Understandability	Appeared occasionally and referred to clarity and readability of models for assessment.

Consequences and proposed solutions

Using the same categories, it is evident that consequences most often accompany Workflow Interruptions and Validation, Layout and Alignment, and Operability and Manipulation, typically describing increased modelling time, reduced task completion, and reduced satisfaction.

Furthermore, proposed solutions most frequently cluster under Operability and Manipulation and Workflow Interruptions and Validation, including concrete workflow adjustments and evaluation practices, with a smaller group referencing Learnability and Discoverability by mentioning training or guidance.

3.2 Grey literature

From the grey literature sources, candidate business process modelling tools were shortlisted. The set included the current tooling in the TEE, Bizagi (desktop version), and an initial list for synthesis: Activiti, ADONIS Community Edition, ARIS Basic, BPMN Studio, BPMN.io (from Camunda), Cawemo (from Camunda), Camunda, HEFLO, Lucidchart, SAP Signavio Process Manager, Visio, and Draw.io.

Each tool was analysed against feature offerings aligned to the entry requirements in section 1.2.2, namely BPMN 2.0 support, availability at no cost, and export quality suitable for document inclusion, with preferred but non-mandatory attributes, co-modelling capability and cloud access without installation. Multi-Criteria Decision Analysis (MCDA) provided a ranking procedure for the tools. A one-point rating scale was applied to each feature, where 0 denotes no support, 0.5 denotes partial support, and 1 denotes full support. Tools were then scored feature by feature where the feature weights were assigned according to the importance defined by the TEE in focus. The resulting ratings on the existing tooling found can be seen in Table 8.

Table 8: Business process modelling tools rating

		Features			*Nice-to-haves*	
Weighting		0.3	0.3	0.2	0.15	0.05
Criteria		BPMN 2.0	Free-to-use	High quality image rendering	Participative modelling with a co-modeler	Cloud-based
1	Bizagi (Desktop Version)	1	0.5	1	0.5	0
2	Activiti	1	1	1	0.5	1
3	ADONIS: Community Edition	1	1	0.5	1	1
4	ARIS Basic	1	0.5	0.5	0.5	1
5	BPMN Studio	1	1	0.5	0.5	0.5
6	BPMN.io	1	0.5	1	0.5	0.5
7	Cawemo	1	0.5	1	1	1
8	Camunda	1	1	1	1	1
9	HEFLO	1	1	1	1	0.5
10	Lucidchart	1	0.5	1	0.5	1
11	SAP Signavio Process Manager	1	1	1	1	1
12	Draw.io	1	1	1	1	1
13	Visio	1	0	1	0.5	1

The ratings were next multiplied by the weight criterion of the features. These were then summed across all features, and a performance rating derived by dividing the sum by a hypothetical perfect tool. The resulting performance ratings, seen in Table 9, indicate the likelihood of the tools having the necessary features needed by the TEE.

Table 9: Performance scores of business process modelling tools

		Features			*Nice-to-haves*		
Weighting		0.3	0.3	0.2	0.15	0.05	
Criteria		BPMN 2.0	Free-to-use	High quality image rendering	Participative modelling with a co-modeler	Cloud-based	Performance Score
1	Bizagi (Desktop Version)	0.3	0.15	0.2	0.075	0	0.73
2	Activiti	0.3	0.3	0.2	0.075	0.05	0.93
3	ADONIS: Community Edition	0.3	0.3	0.1	0.15	0.05	0.90
4	ARIS Basic	0.3	0.15	0.1	0.075	0.05	0.68
5	BPMN Studio	0.3	0.3	0.1	0.075	0.025	0.80
6	BPMN.io	0.3	0.15	0.2	0.075	0.025	0.75
7	Cawemo	0.3	0.15	0.2	0.15	0.05	0.85
8	Camunda	0.3	0.3	0.2	0.15	0.05	1.00
9	HEFLO	0.3	0.3	0.2	0.15	0.025	0.98
10	Lucidchart	0.3	0.15	0.2	0.075	0.05	0.78
11	SAP Signavio Process Manager	0.3	0.3	0.2	0.15	0.05	1.00
12	Draw.io	0.3	0.3	0.2	0.15	0.05	1.00
13	Visio	0.3	0	0.2	0.075	0.05	0.63

4 REQUIREMENTS EXTRACTION RESULTS

This section elaborates on the themes that were extracted from the MLR, in answering DQ4 and DQ5.

4.1 Non-functional requirements for tooling

Efficiency: Reduce effort and time to complete standard modelling tasks in the tertiary context where evidence for Efficiency as a recurring concern appears across multiple studies [5], [18] - [21]. Requirements implied by this theme include minimisation of manual operations during element placement and connection, provision of reliable shortcuts, and removal of avoidable interruptions during save or validation operations. The theme, therefore, supports a requirement that typical undergraduate modelling tasks can be completed with minimal actions and without repetitious confirmation prompts or unstable behaviour.

Effectiveness: Support accurate and complete task attainment in accordance with prescribed modelling outcomes where evidence for Effectiveness is frequent [5], [19] - [21]. Requirements implied by this theme include clarity of element functions, dependable validation feedback that guides correction rather than interrupts flow, and coverage of the notation needed to achieve the intended exercise outcomes. The theme, therefore, supports a requirement that the tool afford correct use of notation elements with feedback on model completeness. This maps to Operability and Manipulation, and Assessment and Understandability, since ambiguous controls and fragile connections undermine model correctness and degrade grading clarity.

Satisfaction: Sustain a positive perceived experience during and after modelling tasks where evidence is present across the extraction [5], [18], [20] - [22]. Requirements implied by this theme include pleasant visual rendering of diagrams, smoothness of interaction, and absence of friction during routine save and export activities. The theme, therefore, supports a requirement that user experience quality not deteriorate under common

classroom workloads. This targets Interface density and Clarity, and Export and Documentation quality, because visual clutter, label collisions, or low-resolution exports lower readability and perceived quality.

Learnability: Reduce initial time to proficiency for novice modellers and facilitate self-guided improvement [5], [20], [22] - [29]. Requirements implied by this theme include recognisable icons, informative tooltips, discoverable palettes, and in-product help resources that align with classroom tasks. The theme, therefore, supports a requirement that onboarding aids be available within the interface rather than through external materials only. This maps to Learnability and Discoverability, and Operability and Manipulation, since weak discoverability raises error rates during basic placement and connection and delays progression to higher order modelling.

Context of use: Fit for tertiary settings in terms of access, licensing, and assessment workflows, with evidence shown in multiple studies [21], [22], [25], [27], [30] - [33]. Requirements implied by this theme include zero-cost access for students, low-friction authentication, and export formats suitable for inclusion in assignments. The theme, therefore, supports a requirement that the tool operate reliably within a common space such as a lab, has remote access conditions and that outputs integrate into the assessment without additional steps. This maps to Access and Authentication, Stability and Save errors, and Assessment and Understandability, because login friction, unstable saves, and incompatible exports create avoidable barriers to completion.

See Table 10 for a synthesis that maps each non-functional requirement to a tooling problem category and usability dimensions.

Table 10: Non-functional and other requirements mapped to problem categories and usability dimensions

Non-functional requirement	Description	Tooling Problem Category	Usability dimensions
Efficiency	Reduced actions and time for modelling, minimal interruptions during save and validation.	Workflow interruptions and validation, Layout and alignment	Efficiency
Effectiveness	Dependable notation coverage, corrective rather than blocking feedback, support for task completion.	Operability and manipulation, Assessment and understandability	Effectiveness
Satisfaction	Smooth interaction and clear visuals during editing, saving, and exporting.	Interface density and clarity, Export and documentation quality	Satisfaction
Learnability	Discoverable palettes, recognisable icons, informative tooltips, and in-product guidance aligned to undergraduate tasks.	Learnability and discoverability, Operability and manipulation	Learnability
Context of use	Free-to-use access, reliable operation in laboratories and remote settings, document ready exports for assessment.	Access and authentication, Stability and save errors, Assessment and understandability	Context of use
Operability	Reliable selection, movement, grouping, and reconnection of elements.	Operability and manipulation	Efficiency, Effectiveness
Layout and alignment quality	Consistent snap to grid, swimlane alignment, and readable label placement.	Layout and alignment	Efficiency, Satisfaction
Low interruption workflow	Avoidance of repetitive confirmations and disruptive prompts.	Workflow interruptions and validation	Efficiency, Satisfaction
Stability and reliability	Protection from crashes, freezes, and save errors under classroom loads.	Stability and save errors	Satisfaction, Context of use

Non-functional requirement	Description	Tooling Problem Category	Usability dimensions
Interface clarity	Low visual density for rapid novice modeler orientation.	Interface density and clarity	Learnability, Satisfaction
Text handling	Clear labels, avoiding label overlapping, and including spell checking.	Text handling, Assessment and understandability	Satisfaction
Access and authentication	Minimal login friction and reliable connectivity.	Access and authentication	Context of use

4.2 Functional or other requirements for tooling

Tooling requirements implied by the themes include reliable alignment and placement through snap to grid and distribution to reduce manual layout effort and improve assessment readability; connection assistance through stable auto connect and low effort reconnection to maintain task flow; palette search and filtering to accelerate element discovery; integrated help and example templates aligned to undergraduate exercises; export to document-ready formats with adequate resolution; non-blocking validation to surface issues without halting progress; stable save and version behaviour to protect iterative work; low friction authentication for laboratory and remote access; and, optional collaboration for co-modelling and feedback where infrastructure exists. Each capability maps to the corresponding tooling problem category listed in Table 11.

Table 11: Functional and other requirements with problem categories

Functional or other requirement	Reason	Tooling Problem Category
BPMN 2.0	Entry condition for correctness and assessment alignment	Assessment and understandability, Operability and manipulation
Free-to-use	Availability for educational use	Access and authentication, Context of use
Export controls	Correct size and resolution for assignment submission	Export and documentation quality
Alignment and placement tools	Snap to grid, lane alignment, distribution to reduce layout effort	Layout and alignment
Element connection assistance	Stable auto connection and easy reconnection of elements	Operability and manipulation
Palette search and filtering	Quick element discovery and selection	Learnability and discoverability
Integrated help and templates	Guidance aligned to course tasks for first time users	Learnability and discoverability
Optional collaboration capability	Effective lecturer and student sessions for demonstration and feedback	Collaboration and co-modelling
Non-blocking validation	Issues flagged without halting progress	Workflow interruptions and validation
Stable save and version behaviour	Reliable saving during iterative work	Stability and save errors
Low friction authentication	Suitability for laboratories and remote access by students	Access and authentication

4.3 Alignment of study evidence with the experimentation-derived categories

Operability and Manipulation: Multiple studies report difficulties with selection and movement of elements, disconnection of sequence flow during editing, and unintuitive deletion or collapsing of sub-processes [19], [24], [34] - [37]. These studies directly support the experimental observation that operability during modelling is a recurrent source of friction.

Workflow interruptions and Validation: Two studies reference validation prompts and error messages that interrupt modelling flow, aligning with the experimentation finding that save time prompts and confirmations reduce fluency [5], [21].

Layout and Alignment: Some studies include inconsistent snap to grid, misalignment of elements and swimlanes, and label placement [5], [24], [38], [39]. These statements confirm the link between layout mechanics and modelling efficiency as identified in experimentation.

Interface density and Clarity: One study notes that dense or visually cluttered interfaces hinder rapid orientation [34]. Although less frequent than operability or layout items, this category confirms that visual burden contributes to perceived complexity in classroom use.

Stability and save errors: Some problem statements mention unstable behaviour, save errors, and crashes [26], [36], [40] - [43]. This category validates an experimental observation that reliability during saving or editing affects task progression and perceived experience.

Collaboration and Co-modelling: Three studies identify a lack of real-time co-modelling support or limited collaboration features [5], [42], [44]. This category confirms the role of collaboration in teaching activities when modelling tasks require synchronous guidance or feedback.

Export and Documentation quality: One study indicates insufficient export quality for in-document use [5]. This validates the experimentation observation that export functions influence assessment readiness in tertiary workflows.

Spell checking and Text handling: A study also mentions missing spell checking and label overlap [24]. Statements such as these support the experimental observation that text handling affects readability and assessment clarity.

Access and Authentication: One study refers to login prompts and connectivity friction [43]. The presence of this category also complements the context of use emphasis in the results and indicates that access constraints can become barriers in student laboratory or remote settings.

Assessment and Understandability: Some studies refer to clarity and readability of models for assessment purposes and to incomplete assessment of model quality [27], [39], [41], [45] - [47]. This category confirms that tool behaviour and produced artefacts have assessment consequences in tertiary modules.

Convergence between experimentation and literature shows problem categories apply beyond a single instance and supports targeted improvements prioritising operability, layout, and validation workflows to achieve the largest gains in learning and assessment.

4.4 Existing tooling

Identification of existing solution areas and tools proceeded through a feature-based comparison aligned with the minimum requirements in section 1.2.2. Each tool received a rating per feature, and a weighted sum was normalised by a hypothetical perfect score. Sorting by this rating showed three tools at the top tier, namely Camunda, Draw.io, and SAP Signavio Process Manager, with Bizagi Modeller positioned below these alternatives. The result is a clear shortlist that can reduce the confirmed

problem categories without custom development, shift training effort from coping with tool friction to reinforcing modelling outcomes, and streamline assessment through better export quality and, where available, collaboration and sharing.

5 RECOMMENDATIONS AND CONCLUSIONS

The study delivers a comparative synthesis of requirements that affect the usability of free-to-use process modelling tools in tertiary education. Evidence from the literature and experimentation aligns with recurring classes of problems, indicating that tooling problems also exist within the body of knowledge, that is,. Operability, Layout and Alignment, Workflow interruptions, Stability, Access, and Assessment clarity. This is because they recur across the review and experimentation and directly degrade efficiency, effectiveness, satisfaction, and assessment clarity in tertiary modelling tasks.

The discovery questions were answered, where the problem instance was validated through structured experimentation using officially prescribed learning materials. Minimum and preferred requirements suitable for tertiary education were derived with emphasis on usability (effectiveness, efficiency, and satisfaction, supported by learnability and context of use). The original problem statement regarding the absence of a comparative focus on feature offerings and non-functional requirements has therefore been addressed through a clear set of minimum requirements in Table 10 and Table 11. The body of knowledge shows limited comparative work on feature offerings and non-functional requirements for free-to-use process modelling tools, yet includes document recurring categories of tooling problems that align with the experimentation results. The review, therefore, validates the class of problems while addressing the comparative gap by deriving minimum requirements for selection and evaluation in tertiary education. The synthesis provides a sufficient basis for requirement-driven comparison and for targeted improvement of teaching workflows, and recommends three tools as a basis for future evaluation of process modelling tools. Future work will develop a decision-making artefact that enables software selection of an appropriate process modelling tool.

Method constraints related to database coverage, query design, and single-researcher screening are documented in the body of the document. Additional limitations include English-only and recent sources, some sources missing full texts, mixed study types, simple counts that can mislabel items, unclear tool versions in sources, MCDA weights reflecting researcher judgement with little stress testing, findings tied to tertiary settings, and an experiment with one tool and one task.

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7 APPENDIX A: SEARCH STRINGS

The following appendix contains the search strings that were used in accordance with the relevant Discovery Questions.

7.1 Developed search strings targeting DQ2 and DQ4

Table 12 below presents the original search strings defined by the discovery questions where the subsequent subsections report repository specific implementations of the strings.

Table 12: DQ2 and DQ4 search strings

Original (“systematic literature review" OR “SLR” OR "systematic review" OR "systematic mapping") AND (“process model* tool" OR "business process model* tool" OR "BPM tool" OR "business process model* software" OR "process model*software" OR "workflow model*tool") AND (“compar*” OR “decision” OR “decision-making” OR “decision analysis” OR “choosing” OR “choice” OR “selecting” OR “select” OR “top” OR “best” OR “feasibility” OR “candidate matrix” OR “candidate screening” OR “alternative matrix” OR “alternative screening” OR “pairwise comparison” OR “analytic hierarchy” OR "ranking" OR "evaluation") AND ("tertiary education" OR "higher education" OR "university" OR "post-secondary" OR "college") AND ("free-to-use" OR "open-source" OR "freeware" OR "open access" OR "non-commercial use")
Relaxed ("systematic review" OR "SLR" OR "literature review") AND ("process modeling" OR "BPM" OR "workflow modeling") AND ("comparison" OR "evaluation" OR "selection" OR "decision") AND ("education" OR "university")

7.1.1 SpringerLink

Original string

("systematic literature review" OR "SLR" OR "systematic review" OR "systematic mapping")

AND ("process modeling tool" OR "business process modeling tool" OR "BPM tool" OR "business process modeling software" OR "workflow modeling tool")

AND ("comparison" OR "decision" OR "decision making" OR "decision analysis" OR "choosing" OR "choice" OR "selecting" OR "selection" OR "top" OR "best" OR "feasibility" OR "candidate matrix" OR "candidate screening" OR "alternative matrix" OR "alternative screening" OR "pairwise comparison" OR "analytic hierarchy" OR "ranking" OR "evaluation")

AND ("tertiary education" OR "higher education" OR "university" OR "post-secondary" OR "college")

AND ("free to use" OR "open source" OR "freeware" OR "open access" OR "non commercial use")

Relaxed string

("systematic literature review" OR "SLR" OR "systematic review")

AND ("process modeling tool" OR "business process modeling tool" OR "BPMN tool" OR "process modeling software" OR "business process modeling software")

AND ("comparison" OR "tool selection" OR "tool evaluation" OR "feature comparison" OR "usability analysis")

7.1.2 Scopus

Original string

TITLE-ABS-KEY("systematic literature review" OR SLR OR "systematic review")

AND TITLE-ABS-KEY("process model*" OR "business process model*" OR BPMN OR "workflow model*")

AND TITLE-ABS-KEY(compar* OR "tool selection" OR "tool evaluation" OR "feature comparison" OR usability)

AND TITLE-ABS-KEY(educat* OR university OR college)

AND TITLE-ABS-KEY(free OR "open-source" OR freeware OR "open access")

Relaxed string

TITLE-ABS-KEY("systematic literature review" OR SLR OR "systematic review")

AND TITLE-ABS-KEY("process model*" OR "business process model*" OR BPMN)

AND TITLE-ABS-KEY(compar* OR "tool selection" OR "tool evaluation" OR "feature comparison" OR "usability")

7.1.3 IEEE Xplore

Original string

("systematic literature review" OR "systematic review" OR SLR)

AND (“process model*” OR “business process model*” OR BPM OR “workflow model*”)

AND (compar* OR evaluat* OR select* OR decision)

AND (educat* OR university OR college)

AND (“open-source” OR freeware OR “open access” OR free)

Relaxed string

(“systematic review” OR SLR OR “literature review”)

AND (“process model*” OR BPM OR “workflow model*”)

AND (compar* OR evaluat* OR select* OR decision)

AND (educat* OR university)

7.2 Developed search strings targeting DQ4 sub questions

Table 13 below presents the original search strings defined by the discovery questions where the subsequent subsections report repository specific implementations of the strings.

Table 13: DQ4 sub questions search string

Original ("usability" OR "user experience" OR "UX" OR "user interface" OR "learnability" OR "ease of use" OR "human-computer interaction") AND (“process model* tool" OR "business process model* tool" OR "BPM tool" OR "business process model* software" OR "process modelling" OR "process model*" OR "business process model*" OR "BPMN" OR "workflow model*") AND ("software selection" OR "tool selection" OR "software evaluation" OR "software tools" OR "modelling tools" OR "process modelling software" OR "BPM tools" OR "educational software") AND (“compar” OR “decision” OR “decision-making” OR “decision analysis” OR “choosing” OR “choice” OR “selecting” OR “select” OR “top” OR “best” OR “feasibility” OR “candidate matrix” OR “candidate screening” OR “alternative matrix” OR “alternative screening” OR “pairwise comparison” OR “analytic hierarchy”) AND ("free-to-use" OR "open-source" OR "freeware") AND ("tertiary education" OR "higher education" OR "university" OR "post-secondary" OR "college")
Relaxed ("usability" OR "user experience") AND ("process modeling tools" OR "BPM") AND ("software evaluation") AND ("free" OR "open-source") AND ("comparison" OR "selection" OR "decision") AND ("education")

7.2.1 SpringerLink

Original string

(“usability” OR “user experience” OR “UX” OR “user interface” OR

"learnability" OR "ease of use" OR "human-computer interaction" OR HCI)

AND ("process model* tool" OR "business process model* tool" OR "process modeling software" OR "process modelling software" OR "workflow model*" OR "BPMN" OR "BPMN tool*" OR "BPM tool*" OR "business process model* software")

AND ("software selection" OR "tool selection" OR "software evaluation" OR "software tools" OR "modelling tools" OR compar* OR "decision" OR "decision-making" OR "decision analysis" OR "choosing" OR "choice" OR "selecting" OR "select" OR "feasibility" OR "candidate matrix" OR "candidate screening" OR "alternative matrix" OR "alternative screening" OR "pairwise comparison" OR "analytic hierarchy" OR AHP)

AND ("free-to-use" OR "open-source" OR "freeware")

AND ("tertiary education" OR "higher education" OR "university" OR "post-secondary" OR "college")

Relaxed string

("usability" OR "user experience" OR UX)

AND (BPMN OR "process model*" OR "workflow model*" OR "process modeling software" OR "BPM tool*")

AND (comparison OR "tool selection" OR "software evaluation")

7.2.2 Scopus

Original string

TITLE-ABS-KEY(("usability" OR "user experience" OR UX OR "user interface" OR learnability OR "ease of use" OR "human-computer interaction" OR HCI) AND ("process model* tool" OR "business process

model* tool" OR "process model* software" OR "workflow model*" OR BPMN OR "BPMN tool*" OR "business process model* software" OR (BPM W/3 (tool* OR software OR model* OR notation)))

AND ("software selection" OR "tool selection" OR "software evaluation" OR "software tools" OR "modelling tools" OR compar* OR decision OR "decision-making" OR "decision analysis" OR choosing OR choice OR selecting OR select OR feasibility OR "candidate matrix" OR "candidate screening" OR "alternative matrix" OR "alternative screening" OR "pairwise comparison" OR "analytic hierarchy" OR AHP))

Relaxed string

TITLE-ABS-KEY(("usability" OR "user experience" OR UX OR "ease of use" OR learnability OR readability OR understandability OR "human-computer interaction" OR HCI OR "visual notation" OR "cognitive load")

AND ("process model*" OR "business process model*" OR "workflow model*" OR BPMN OR "process diagram*" OR "process map*")

AND (compar* OR evaluat* OR assessment OR "case study" OR "empirical study" OR benchmark* OR select* OR "decision*"))

7.2.3 IEEE Xplore

Original string

(("usability" OR "user experience" OR "UX" OR "user interface" OR learnability OR "ease of use" OR "human-computer interaction" OR HCI)

AND ("process model* tool" OR "business process model* tool" OR "process modeling software" OR "workflow model*" OR "BPMN" OR "BPMN tool*" OR ("BPM" NEAR/3 (tool* OR software OR model* OR notation)))

AND ("software selection" OR "tool selection" OR "software evaluation"

OR “software tools” OR “modelling tools” OR compar* OR decision OR “decision-making” OR “decision analysis” OR choosing OR choice OR selecting OR select OR feasibility OR “pairwise comparison” OR “analytic hierarchy” OR AHP))

Relaxed string

((usability OR “user experience” OR UX OR “ease of use” OR learnability OR readability OR understandability OR HCI OR “quality in use”)

AND (BPMN OR “process model*” OR “workflow model*” OR “business process model*” OR BPM OR “process diagram*” OR “process map*”)

AND (compar* OR evaluat* OR assessment OR benchmark* OR select* OR “decision*” OR “case study”))