User Interface Design Research for Modeling Tools

A Literature Study

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Abstract. *Modeling tools constitute a class of software assisting modelers in creating, documenting, and maintaining conceptual models, for example, via graphical editors, diagram layouting, and syntax checking. Research on modeling tools has been a recurring theme in conceptual modeling research for more than 30 years. An evident focus in modeling tool research is on user interface design. In this literature study, we systematically identify and analyze 72 contributions to user interface design research for modeling tools published between 1980 and 2017 to develop a structuring overview of the current state of research. Building on this overview, we assess and discuss promising paths for future research, and compile recommendations informing user interface design of modeling tools.*

Keywords. Modeling Tool • Conceptual Modeling • User Interface Design • Literature Study

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1 Introduction

Conceptual modeling research has for long studied the design and use of modeling tools, i. e. software tools supporting modelers while creating, documenting and maintaining conceptual models (e. g., Frank 1999; Frank et al. 2013). Modeling tools are essential for practicing conceptual modelers and software engineers to increase their productivity (e. g., Recker 2012), and to benefit from (semi-)automation, e. g., by tool-supported code generation. Modeling tools such as the former Rational Rose or ARIS Toolset have helped to create, improve and refine thousands of conceptual models, and have demonstrated the usefulness of modeling tools at various stages of the software engineering process.

One particular focus of modeling tool research pertains to the design of (graphical) user interfaces for modeling tools. Design objectives of this research focus include, for instance, to facilitate tool learning and tool use, e. g., by providing intuitive user interface paradigms and elements, and to provide targeted support and assistance for modeling activities, e. g., by suggesting modeling concepts via display of corresponding graphical symbols on a modeling canvas (Becker et al. 2013; Frank et al. 2013).

Despite the proliferation of modeling tools in practice and their relevance for scientific research, surprisingly few overviews of the design of modeling tools are available (e. g., Frank et al. 2013). Although numerous publications point out that user interfaces still need improvement (e. g., Trojahner et al. 2010; Voigt et al. 2013), design recommendations and documented results on the design of user interfaces are rare. However, design recommendations provide an opportunity to support the development of modeling tools, in particular to build on existing research and prior knowledge. Besides, current surveys on the use of modeling tools suggest a need for further research on modeling tools (e. g., Trojahner et al. 2010; Voigt et al. 2013)—in particular comprehensibly

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presented recommendations for the design of user interfaces for modeling tools (Frank 2014).

The present comprehensive literature study contributes to filling this research gap by systematically compiling and analyzing prior work in modeling tool research reporting design studies and design recommendations to provide a structuring overview of research in this field—to support cumulative research on modeling tools and to inform practitioners with a current state of the art. For this purpose, the study is guided by three questions:

- *Which user interfaces are currently implemented in conceptual modeling tools?*
- *Which design recommendations for the design of user interfaces in modeling tools are devised in research literature?*
- *Which themes or phenomena are emerging in research on user interfaces of modeling tools?*

Based on the literature study, we identify research gaps and discuss potential paths for future research on user interface design for modeling tools (following, e. g., Fettke 2006). Our study is based on a systematic literature search that combines pluralistic search strategies and aims to consider relevant contributions published between 1980 and 2017 as comprehensively as possible (following, e. g., Fettke 2006; vom Brocke et al. 2009, 2015; Webster and Watson 2002). The research design is not limited to publications from a specific field of knowledge nor a particular type or genre of published work. However, we do not consider (vector-oriented) drawing and visualization software as modeling tools if they do not offer any further support for conceptual modeling beyond the manipulation of graphical symbols on a drawing canvas.

In the following section, we discuss related work. Afterward, the theoretical background is outlined in Sect. 3. Sect. 4 reports on the research design, including literature retrieval, literature analysis, and methodical limitations. In Sect. 5, descriptive findings are presented following the structure provided by the analytic questions. A detailed discussion of findings is provided in Sect. 6. The review concludes by proposing directions for future research and a reflective commentary (Sect. 7).

2 Related Work

Only very few literature studies address design recommendations for modeling tools. Prior review research has rather addressed the usability of modeling tools, e. g., with a focus on process modeling tools (Becker et al. 2013; Shitkova 2014; Thaler et al. 2015, 2018). However, other relevant aspects as the design of user interfaces, especially, supportive and facilitating modeling tool functions were widely excluded. For example, preliminary findings of Becker et al. (2013, p. 7) propose a theoretical usability measurement framework for assessing the usability of process modeling tools. On that basis, Shitkova (2014) focuses on Business Process Management (BPM) tools and discusses future paths and research opportunities for the topic of usability of BPM tools. An overview of modeling tools used for conceptual modeling in practice is presented in (Fettke 2009). Broadly, the study shows that the usage of conceptual modeling tools had increased with a focus on a few widely used tools. Regarding the design of user interfaces of modeling tools, Fettke (2009) hypothesizes that the complexity of modeling tools harms the acceptance of modeling languages—especially because prospective users become discouraged by the sheer degree of functionality of a modeling tool (Fettke 2009, pp. 584–586). Further contributions related to conceptual modeling tools only rarely and implicitly discuss the design of user interfaces, e. g., with respect to knowledge-based modeling tools (e. g., Wand and Weber 2002). In contrast to prior work, the present study performs a comprehensive review on the design of modeling tools with a focus on the design of user interfaces. Please note that this study is not restricted to software tools supporting a specific kind of conceptual modeling as, for example, business process modeling (e. g., Becker et al. 2013; Shitkova 2014).

The design of user interfaces is closely related to the concept of usability. The usability of a modeling tool describes the ease of use by which a user can work with a modeling tool to achieve modeling goals adequately and effectively—playing an important role in practice for the acceptance of conceptual modeling (see Becker et al. 2013). Often, usability is denoted as a "measure" of user satisfaction when a modeler is using a modeling tool, or more generally a software system (e. g., Tarkkanen and Harkke 2019, p. 138–140). Usability is a widely used term in software engineering, user interface design, and software quality. There are a number of conceptualizations of usability (cf. Becker et al. 2013, p. 2). The most common definition of the term "usability" is provided by the standard series ISO 9241 (ISO 2006), which additionally comprises design recommendations regarding the design of user interfaces, their usability and evaluation guidance (e. g., ISO 9241-11, ISO 2018). Following the ISO 9241-11, usability is the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use (cf. ISO 2018). However, for conceptual modeling and thus modeling tools, the term usability requires further specific considerations regarding modeling approaches and modeling conventions (e. g., Jörg Becker et al. 2009), e. g., data modeling with the Entity-Relationship Model (ERM) (Chen 1976) requires that entity types should specify at least one attribute. On the one hand, the ISO 9241 (ISO 2006) includes guiding criteria for evaluating the usability of software that depends on the context of use (ISO 9241-11, ISO 2018) by providing multiple usability attributes (e. g., Bastien 2010; Nielsen 1993; Seffah et al. 2006). On the other hand, further usability measurement frameworks, e. g., proposed by Shackel (2009), take the user, task, tool and environment into consideration—which is required for usability measurement (Bastien 2010). However, the guidance for evaluating modeling tools provided by standards such as the ISO 9241 remain abstract, e. g., for the design of modeling tools regarding specific integrated modeling or learning (tool) support. Furthermore, generic usability measurement frameworks do not take into account the particularities of conceptual modeling tools, e. g., of process modeling tools (cf. Becker et al. 2013, p. 1).

Altogether, the majority of related work addresses the topics of usability and modeling tool support with only few contributions focusing on user interfaces of modeling tools. Furthermore, prior work is limited to, e. g., syntax checking and modeling grammar (e. g., Recker 2012), research on (knowledge-based) modeling tools (e. g., Fettke 2009; Wand and Weber 2002), and prototyping (e. g., Alpers and Hellfeld 2016; Brown et al. 2011; Derntl et al. 2015). In particular, design recommendations have only rarely been addressed in prior work. Hence, a systematically consolidated knowledge base providing implications for the design of user interfaces as well as construction-oriented research is missing at present.

3 Theoretical background

The user interface of a modeling tool includes interaction elements and implements interaction paradigms. The term *interaction paradigm* refers to how users interact with a tool, e. g., adding a (graphical) notation symbol to a modeling canvas by using the interaction gestures *drag & drop* (e. g., Nicolaescu et al. 2017) or *point & click* (e. g., Bork and Sinz 2013). However, different interaction paradigms can be combined in one user interface. With respect to modeling tools, the user interface typically comprises a graphical interface that enables users using targeted functions to perceive and control the reactions of the modeling tool, i. e. the behavior. The input options (e. g., keyboard, mouse, language, motion gestures) and the output options (e. g., screen) of a user interface are emphasized here in particular. In modeling tools, the user interface provides a graphical editor (according to the metaphor "paper") and often a palette of notation symbols representing the implemented modeling language respective modeling method—a clear separation of the implementation is difficult, since the implementation of a modeling method should also provide the possibility to check the model for syntactical correctness.

Very broadly speaking, (modeling) tools that provide graphical editors implement a *graphical user interface* (GUI, e. g. Cooper et al. 2014). Graphical user interfaces support the use of graphical metaphors for objects, e. g., pictograms or symbols for functions (e. g., filing cabinets with folders in drawers) that support the understanding of relationships between user interface elements and tool behavior. Mouse-based operations aim at the concept of direct manipulation by providing visual feedback and are typical for (modern) GUI-based (modeling) tools. Besides, other hardware input devices can also be used, e. g., voice input with microphones or headsets to control parts of the GUI or as an operating principle. The ability to select and modify elements on the screen is fundamental to the user interfaces designed today.

Natural User Interfaces (NUI) are used for touch-sensitive input devices, e. g., touchscreens such as tablets or electronic whiteboards. These NUI enable users to interact directly with a touch-sensitive user interface through gesture control and, if necessary, voice input. Interaction paradigms can include the so-called "one-line gesture" (Alpers and Hellfeld 2016) that supports the creation of notation symbols on the drawing area using simple gestures, e. g., a circle for a transition of a Petri net (Alpers and Hellfeld 2016) or a rectangle for a BPMN activity (Kolb 2015). *Tangible user interfaces* (TUI) make us of tangible physical objects that link functions and information with physical object properties, i. e. notation symbols are manipulated by physical objects (e. g., Ionita et al. 2015).

User interfaces based on *virtual reality* (VR) aim at the three-dimensional representation of conceptual models in modeling tools and corresponding user paradigms for spatial orientation. *Augmented reality* (AR) user interfaces add information to images (in motion) to facilitate the creation of conceptual models (e. g., Metzger et al. 2017). VR-based approaches include the representation of three-dimensional computer graphics in virtual environments with which users can interact using head and hand movements, gestures, and verbal commands. VR-based approaches also include modeling tools that are based on a GUI but focus on three-dimensional model representation as, for example, addressed in (Betz et al. 2008) or three-dimensional-based environments in which the user can interact, e. g., as an avatar (e. g., Brown 2010). In contrast to VR-based user interfaces, AR-based approaches integrate physical and virtual environments by optically overlaying the images of the real environment with virtual objects. For the creation of conceptual models, additional information, e. g., on process steps, is provided by supplementary video clips (e. g., Poppe et al. 2012). In addition, *text-based user interfaces* are proposed, which are specifically aimed at supporting users with visual impairment in creating conceptual models. For instance, Braille keyboards or voice inputs, as well as voice outputs, are used as input devices. Navigation within the user interface and in the conceptual model is also performed text-based.

4 Research design

The present study constitutes a standalone and intentionally comprehensive literature review aimed at a state-of-the-art review in the field of user interfaces in conceptual modeling tools (following, e. g., Fettke 2006 and vom Brocke et al. 2009). For the literature retrieval, selective searches in selected journals and conference proceedings, searches in electronic databases as well as forward, backward and author searches were purposefully combined (following, e. g., Webster and Watson 2002 and Fettke 2006) in order to include not only publications in journals and conference proceedings, but also, for instance, monographs and contributions in anthologies (for an overview, see Fig. 2). The database searches and selective searches in journals and conference proceedings include the time frame from 1980 to April 2017 which includes the popularization of the GUI in the 1980s (designers create icons and other visual elements, e. g., the original Mac OS, see Cooper et al. 2014, p. 6). We assume that backward or author

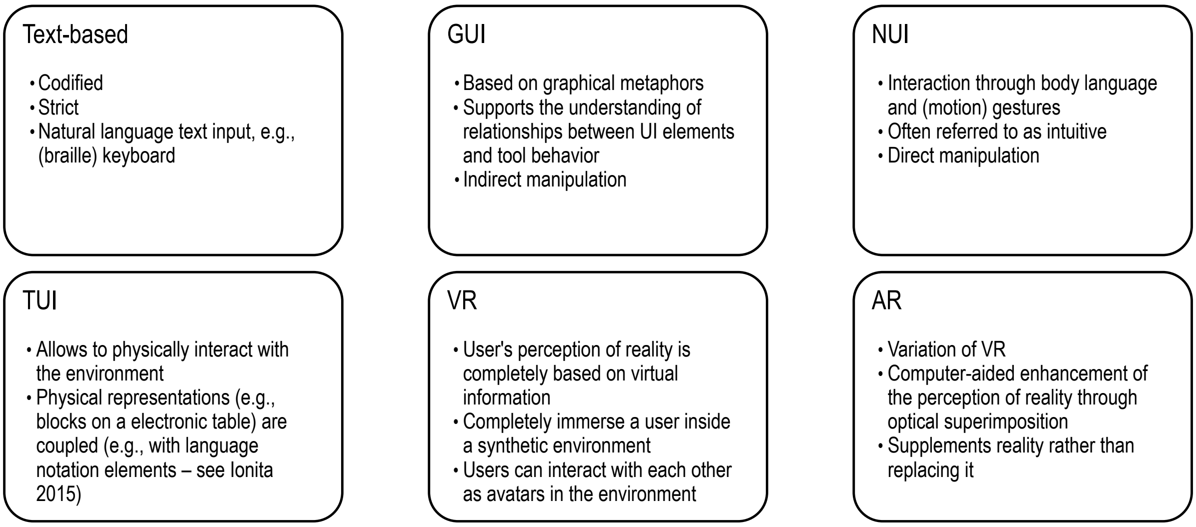

Figure 1: Essential UI categories.

searches identify relevant work published before 1980. The search is limited to results published in the English and German languages.

4.1 Literature retrieval

The first step of the literature retrieval comprised searches in selected journals and conference proceedings (an overview is shown in Tab. 1). The selection of sources includes relevant outlets at the core of the Business and Information Systems Engineering and Information Systems communities including sources affiliated with associations pertinent to the communities, including 7 journals (ISR, MISQ, JIMS, EJIS, BISE/WI, EMISAJ, CAIS), 7 conference proceedings (ICIS, ECIS, ER, WI, HICSS, PACIS, AMCIS) and 2 anthologies (LNCS, LNI). Note that further relevant conferences such as the International Conference on Business Process Management (BPM), the International Conference on Conceptual Modeling (ER) and the International Conference on Advanced Information Systems Engineering (CAiSE) are part of the LNCS. Conference proceedings are considered to account for more recent publications. As user interfaces are a central research topic in the field of Human-Computer Interaction (HCI), the selection of journals and conference proceedings was complemented by 5 further journals (TOCHI, H-CI, BIT, IJHCS, THCI) and 4 conference proceedings (CHI, INTERACT, IUI, HCI) which are regarded as relevant for the focus of the present study from a HCI perspective (e. g., Coursaris and Bontis 2012). Altogether, searches were performed in a selection of 12 journals, 11 conference proceedings, and 2 anthologies (see Tab. 1).

To derive a generic search term, we performed initial test searches which demonstrated principle limitations with database searches, for instance, either proved too limited, e. g., with keywords such as “modeling tool user interface” nor produced far too many results irrelevant for this literature study, e. g., “modeling tool” AND “user interface”. Hence, we complement these keywords with further keywords such as “usability” and “modeling”, because many relevant publications of the initial test searches also indexed these keywords. Based on the focus and research objectives of the study, we purposefully constructed and tested the following combination of German and English keywords as a generic search term for the searches in journals, anthologies and conference proceedings:

```
gestalt* (desig*) OR entwickl*
(develop*) OR evalu* (evaluat*)
```

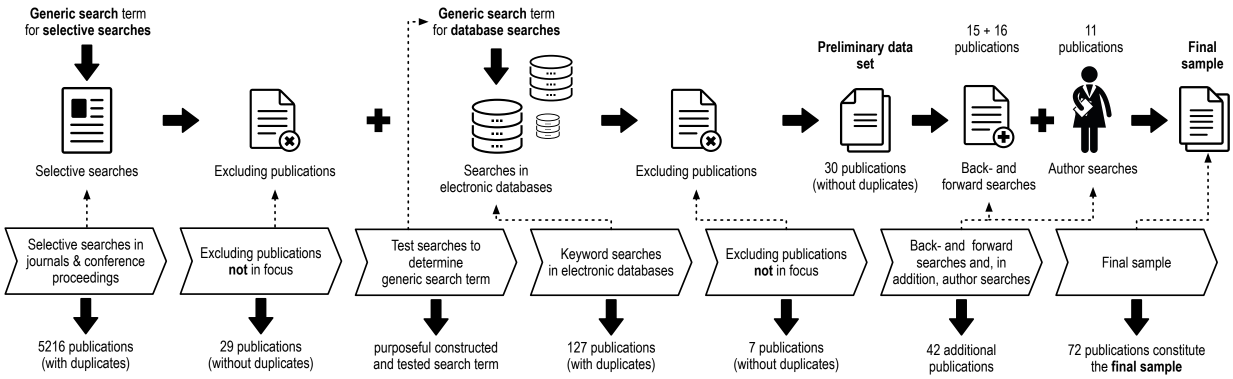

Figure 2: Literature retrieval.

```
OR interaction (interaction)
OR usability (usability)) AND
(interface) OR user (user))
AND (modeling or modelling) AND
(tool) OR software (software)
OR system (system) OR module
(module) OR application
```

This term was used for searches in the search field "Abstract" tailored to the respective search query syntax. tailored to the respective search query syntax. If a search in this field was not possible (due to technical restrictions of the search forms and /or database), a search was performed in the search fields 'Title', 'Abstract' and 'Keywords' or, if this was also not possible, a full-text search was carried out with an adapted search term (see Fig. 3). The results of the searches were reviewed concerning their relevance to the focus of the present study. In this respect, the following inclusion criteria had to be fulfilled by a publication to be included in the review sample:

(1) The contribution must be a German or English language research contribution.

(2) The contribution must focus on the design of user interfaces in modeling tools for conceptual modeling.

(3) The contribution must be an original research contribution.

Hence, book reviews, editorials, keynotes, tutorials, conference summaries, research notes, or workshop descriptions were excluded, (e. g., Frank 2014). Likewise, contributions with other foci were excluded, e. g., with a focus on the design of graphical notations for process modeling (e. g., Koschmider et al. 2016). For assessing the fulfillment of the inclusion criteria, the title, abstract and, if necessary, the full-text of a contribution was considered. Fig. 3 illustrates an overview of the performed searches. Altogether, the selective searches led to 29 results relevant for the focus of the present review.

The second step of the literature search comprised searches in 7 electronic databases (see Fig. 3). Based on the results of selective searches and as a result of test searches performed in the databases, the following combination of English keywords was constructed as a generic search term for database searches:

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interface AND "modeling tool"
OR "modelling tool" OR "modeling
software" OR "modelling software"
AND conceptual
```

The generic search term was tailored to the search query syntax of each electronic database. The results of the searches were assessed for the fulfillment of the set inclusion criteria, taking into account the title, abstract and, if necessary, the full text of a contribution. The selection of the databases aims to cover the literature as comprehensively as possible and, therefore, comprises a cross-disciplinary database, i. e., EBSCOhost (Business Source Ultimate, Econ Lit, Information and Technology, SocINDEX), Scopus (indexing LNCS, SoSym, etc.), Web of Science (core collection), ScienceDirect complemented with searches in core databases on the Information Systems and Computer Science disciplines, i. e., Association for Information Systems Electronic Library (AISel), ACM Digital Library and IEEE Xplore Digital Library. In this second step, 7 further publications were identified as relevant. Without duplicates, the selective searches and the database searches resulted in an intermediate sample of 30 publications.

To include further relevant publications, e. g., monographs, and articles published in anthologies, the previous searches were supplemented by forward, backward, and author searches based on the interim results. For this purpose, the bibliographies of all publications in the intermediate sample were scrutinized by the first two authors and one student and assessed regarding the fulfillment of the set inclusion criteria which required a consensus among the first two authors. Besides, we assessed the results of forward searches performed with the Scopus database and the Google Scholar search engine as well as the results of author searches using the Scopus database based on the 30 results in the intermediate sample based on the inclusion criteria. Titles, abstracts, and, if necessary, the full texts of the contributions were considered. A total of 15 publications were identified as relevant for the focus of this study in the backward searches, 16 publications in the forward searches and 11 publications in the author searches, resulting in a final sample of 72 publications. The bibliographical information of all publications in the final sample is attached as supplementary material for further use (see Appendix A).

4.2 Literature analysis

In a first step, we analyze the data set regarding the number of publications over time and of modeling languages supported by modeling tools (publication profile). We then apply the following criteria and analytic questions to achieve a structuring overview of prior research on designing user interfaces of modeling tools (Levy and Ellis 2006, p. 199; Fettke 2006, pp. 260f):

(C1) User interface(s) applied in modeling tools

This first analysis criterion examines which user interfaces are implemented in modeling tools (cf. Sect. 3). A first selective review of literature on user interfaces in modeling tools suggested that different kinds of user interfaces are applied (e. g., GUI, NUI)—exhibiting differences in interaction possibilities for modelers and, partly, accompanied by promises of enhanced handling. To this end, we compile user interface in modeling tools and organize publications in the review sample according to the applied user interface. This criterion aims to achieve an organizing overview of user interfaces in research on modeling tools and, hence, addresses the following question: *Which user interfaces are currently implemented in conceptual modeling tools?*

(C2) Design recommendations for user interfaces in modeling tools

The second criterion compiles recommendations for the design of user interfaces in modeling tools. We conceptualize recommendations for the design of user interfaces *(design recommendations)* as design guidelines and design principles that have been applied and evaluated. They are aimed at the design of user interfaces in modeling tools and aim to provide suggestions and hints for the design of modeling tools and their user interface. Recommendations considered in the research at hand also include national and international standards that provide specific recommendations for the consistent design of a software tool (e. g., the ISO 9241 series of standards consisting of a total of 336 recommendations for the design of user interfaces in general, see ISO 2006). The second criterion also examines whether design recommendations refer to standards for software ergonomics or the design of software tools. This criterion of analysis aims at presenting the present state of research on design recommendations and

Category	Sources
IS Journals	Information Systems Research (ISR), Management Information Systems Quarterly (MISQ), Journal of Management Information System (JMIS), European Journal of Information Systems (EJIS), Business & Information Systems Engineering (BISE)/WIRTSCHAFTSINFORMATIK, Enterprise Modelling and Information Systems Architectures (EMISAJ), Communications of the Association for Information Systems (CAIS)
IS Conferences	International Conference on Information Systems (ICIS), European Conference on Information Systems (ECIS), International Conference on Conceptual Modeling (ER), International Conference Wirtschaftsinformatik (WI), Hawaii International Conference on System Sciences (HICSS), Pacific Asia Conference on Information Systems (PACIS), Americas Conference on Information Systems (AMCIS)
HCI Journals	ACM Transactions on Computer-Human Interaction (TOCHI), Human-Computer Intertaction (H-CI), Behaviour & Information Technology (BIT), International Journal of Human-Computer Studies (IJHCS), AIS Transactions on Human-Computer Interaction (THCI)
HCI Conferences	Conference on Human Factors in Computing Systems (CHI), International Conference on Human-Computer Interaction (INTERACT), International Conference on Intelligent User Interfaces (IUI), International Conference on Human-Computer Interaction (HCI)
Anthologies	Lecture Notes in Computer Science (LNCS), Lecture Notes in Informatics (LNI)

Table 1: List of selected journals, conference proceedings and anthologies included in selective searches.

is targeted at answering the following question: *Which design recommendations for the design of user interfaces in modeling tools are devised in research literature?*

(C3) Emerging research themes
Furthermore, we aim at uncovering emerging research themes and phenomena in the analyzed literature (following, e. g., Leidner 2018). Applying an open coding strategy, research themes in the analyzed publications are systematically coded, grouped and iteratively revised during literature analysis, i. e. during the intensive reading of the 72 identified publications, to identify anchor points for a future research agenda on designing user interfaces in modeling tools. Hence, the following question is addressed: *Which themes are emerging in research on user interfaces for modeling tools?*

4.3 Limitations of the literature study

The literature retrieval does not ensure that all contributions potentially relevant to the research objectives of the study are identified—despite the systematic, purposeful sampling procedure (vom Brocke et al. 2009). Moreover, it is possible that disputable decisions were made in the selection of publications or in the exclusion of publications that were not considered relevant. Additionally, the selected research criteria exclude other equally relevant aspects of tool research, e. g., software architecture patterns (e. g., Ritter et al. 2015) or evaluation methods (e. g., Safdar et al. 2015). Furthermore, the usability of user interfaces is not in the focus of this review but is addressed in current articles (e. g., Becker et al. 2013; Shitkova 2014). These aspects offer interesting starting points for further research aimed at providing an overview and in-depth insights regarding other aspects of modeling tool research.

5 Findings

Following a search strategy including not only general IS outlets but also specific outlets including conference proceedings, monographs and an-

IS & HCI Journals	Search fields	Time frame	Hits	Relevant
Information Systems Research (ISR)	‚Abstract‘	1990–2017	8	**0**
Management Information Quarterly (MISQ)	‚Abstract‘	1980–2017	8	**0**
Journal of Management (JMIS)	‚Abstract‘	1984–2017	9	**2**
European Journal of Information Systems (EJIS)	‚Title | Abstract | Keywords‘	1991–2017	30	**0**
Business & Information Systems Engineering (BISE)	‚Abstract‘	2009–2017	7	**0**
WIRTSCHAFTSINFORMATIK (WI)	‚Full-text‘	1999–2014	166	**1**
Enterprise Modelling and Information Systems Architectures (EMISAJ)	‚Abstract‘	2005–2017	1	**0**
Communications of the Association for Information Systems (CAIS)	‚Full-text‘	1999–2017	5	**0**
ACM Transaction on Computer-Human Interaction (TOCHI)	‚Abstract‘	1994–2017	50	**0**
Human-Computer Interaction (H-CHI)	‚Abstract‘	1984–2017	8	**0**
Behaviour & Information Technology (BIT)	‚Abstract‘	1996–2017	13	**0**
International Journal of Human-Computer Studies (IJHCS)	‚Title | Abstract | Keywords‘	1994–2017	72	**1**
AIS Transactions on Human-Computer Interaction (THCI)	‚Abstract‘	2009–2017	5	**0**
IS & HCI Proceedings	**Search fields**	**Time frame**	**Hits**	**Relevant**
International Conference on Information Systems (ICIS)	‚Abstract‘	1980–2017	151	**0**
European Conference on Information Systems (ECIS)	‚Title | Abstract | Keywords‘	1980–2017	92	**2**
International Conference on Conceptual Modeling (ER)	‚Full-text‘	1992–2017	88	**4**
Internationale Tagung Wirtschaftsinformatik (WI)	‚Abstract‘	1999–2017	12	**0**
Hawaii International Conference on Systems Sciences (HICSS)	‚Abstract‘	1988–2017	117	**3**
Pacific Asia Conference on Information Systems (PACIS)	‚Abstract‘	1993–2017	104	**0**
Americas Conference on Information Systems (AMCIS)	‚Abstract‘	1995–2017	179	**1**
Conference on Human Factors in Computing Systems (CHI)	‚Abstract‘	1981–2017	489	**0**
International Conference on Human-Computer Interaction (INTERACT)	‚Full-text‘	2005–2013	19	**1**
	‚Title | Abstract | Keywords‘	2015	0	**0**
International Conference on Intelligent User Interfaces (IUI)	‚Abstract‘	1993–2017	238	**0**
International Conference on Human-Computer Interaction (HCI)	‚Full-text‘	2007–2017	108	**2**
Anthologies	**Search fields**	**Time frame**	**Hits**	**Relevant**
Lecture Notes in Computer Science (LNCS)	‚Full-text‘	1980–2017	2998	**9**
Lecture Notes in Informatics (LNI) (Proceedings, German & English)	‚Full-text‘	2001–2016	209	**6**
Electronic Databases	**Search fields**	**Time frame**	**Hits**	**Relevant**
Association for Information Systems Electronic Library (AISeL)	‚Abstract‘	1980–2017	0	**0**
ACM Digital Library	‚Abstract‘	1980–2017	20	**1**
EBSCOhost (Business Source Ultimate, EconLit, Information & Technology, SocINDEX)	‚Abstract‘	1980–2017	1	**0**
ScienceDirect	‚Title | Abstract | Keywords‘	2007–2017	4	**0**
Scopus	‚Title | Abstract | Keywords‘	1980–2017	53	**2**
IEEE Xplore	‚Abstract‘	1980–2017	20	**2**
Web of Science (core collection)	‚Title | Abstract | Keywords‘	1980–2017	29	**2**
		Duplicates	**#**	**9**
		Sum	**#**	**30**

Figure 3: Search fields, time frame, numbers of search results and results relevant for the focus of this study for selective searches and database searches.

thologies, 72 unique publications (between 1980 and 2017) are identified in the literature search—giving an idea of the size of the body of knowledge in the field of user interface design research for modeling tools. The number of publications has increased considerably over time with the majority of publications published in the past decade (see Fig. 4)—suggesting increased research interest. The final sample entails contributions addressing a variety of modeling methods and modeling languages including BPMN 2.0, UML Activity Diagrams, and (Extended) Event-driven Process Chains (EPC). According to the frequency of occurrence in the final sample, tools supporting process modeling are predominant constituting about a half of the contributions, followed by tools that support object-oriented modeling such as UML (about a fifth of the contributions). The majority of tools supporting process modeling (about three-quarters) refer to BPMN 2.0 (e. g., Döweling et al. 2013; Kolb et al. 2012) and Petri net approaches (e. g., Betz et al. 2008). We count only very few implementations of BPMN 1.x (e. g., Brown et al. 2011), EPC (e. g., Fellmann et al. 2013) and UML activity diagrams (e. g., Lee et al. 2000). Approaches addressing static abstractions (UML class diagrams e. g., Grillo and Fortes 2014b), variants of the Entity-Relationship Model (Dudley 1989) as well as functional abstractions (e. g., IDEF in Dean et al. 1998) are also rarely represented in the data set. The remaining contributions, which account for about one-third of the data set, refer to other modeling languages and further diagram types of UML (e. g., Safdar et al. 2015), or focus on overarching design aspects, e. g., usability, are survey articles, case studies or experimental studies (e. g., Shitkova 2014; Voigt et al. 2013). A further, small subset of the final sample refers to idiosyncratic modeling languages (e. g., Ionita et al. 2015) or domain-specific languages (e. g., Bogdan et al. 2012).

5.1 Applied user interfaces

Reviewing prior work on user interfaces of modeling tools leads us to identify six categories of user interfaces applied in modeling tools: GUI, NUI, TUI, AR-based, VR-based and text-based (see Tab. 2). Additionally, a non-specific category is introduced for contributions that either address more than one of the above mentioned categories or focus other aspects of user interfaces, e. g., the usability of modeling tools and their user interfaces (e. g., Becker et al. 2013; Shitkova 2014).

The majority of the contributions focuses on GUI with 28 contributions—which is not surprising in the light of the proliferation of GUI (see Fig. 4). The identified graphical user interfaces differ mainly in the design of the graphical operating elements (e. g., symbol palettes, modeling canvas). Only a few contributions suggest to align the symbol palette on the right-hand side of the user interface (e. g., Bogdan et al. 2012), and some contributions propose to allow a proper alignment through so-called *widgets* (graphical components) (e. g., Derntl et al. 2014, 2015; Nicolaescu et al. 2013, 2017). The primary user interaction paradigm is the “drag & drop” interaction paradigm to "move" symbols from the palette to the drawing area (e. g., Bogdan et al. 2012) instead of using dialogs and menus. Alternatively, the “point & click” interaction paradigm is used to place modeling elements on the drawing area (Chen et al. 2008; Derntl et al. 2015).

The number of publications based on NUI has significantly increased in the last decade (19 publications) which can be traced back to modeling tools that facilitates collaboration, mobile working and, thus, creating models on touchscreen-based user interfaces (e. g., Alpers et al. 2014; Alpers and Hellfeld 2016). We find NUI predominantly in contributions discussing collaborative modeling in which several modelers work together on conceptual model construction, e. g., by synchronously constructing a conceptual model while exchanging ideas with each other. NUI-based approaches in the final sample differ in terms of the implemented graphical interface and the interaction paradigm, e. g., electronic boards are usually pen-based input devices (Chen et al. 2008) whereas touch-sensitive user interfaces are primarily based on (finger) gestures translated into notation symbols by the

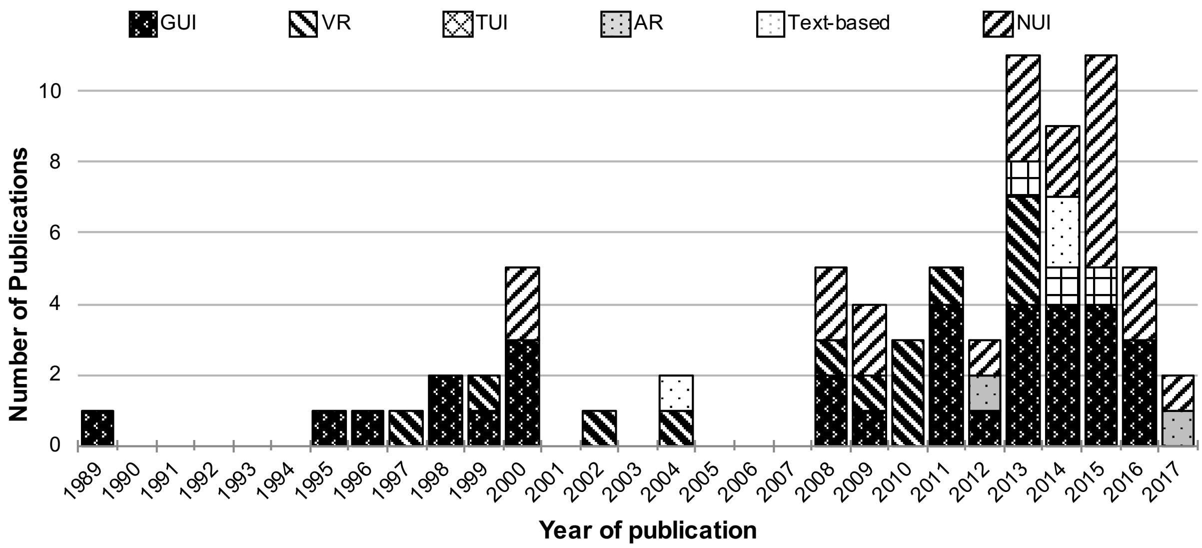

Figure 4: Number of publications in the final sample 1980–2017 distinguished by user interface (non-specific contributions excluded).

modeling tool (Alpers and Hellfeld 2016). Furthermore, so-called auto-adaptive user interfaces based on multiple finger gesture recognition are proposed, e. g., in (Nolte and Gulden 2017). The combination of NUI and GUI is suggested, for example, for (mobile) process documentation to circumvent media disruptions (e. g., Alpers and Hellfeld 2016).

We identify only a single TUI-based modeling tool (Ionita et al. 2015). This approach enriches physical objects with digital information and uses these objects as representations for notation symbols to create a representation of a conceptual model on a special designed electronic table. Base on this representation, a conceptual model is generated.

Furthermore, two articles suggest modeling tools with AR-based user interfaces. Semi-transparent computer-controlled glasses are suggested that provide additional information on (real) process steps by optical superimposition (Poppe et al. 2012). Also based on AR, it is proposed to support process documentation by supporting the creation of a process model by an expert user accompanied by audio and image recordings (Metzger et al. 2017). A surprisingly high number of VR-based approaches is proposed (13 contributions). Contributions that suggest a three-dimensional visualization of conceptual models are included in this category (e. g., Brown et al. 2011). VR-based approaches involve the use of three-dimensional notation symbols to enrich symbols with semantics by adding a further dimension in the visual representation (e. g., Betz et al. 2008; Brown et al. 2011). For example, users can visualize semantic similarities, e. g., with a thickness (more or less bold), between places, transitions, or both (Betz et al. 2008, p. 80). In addition, the whole environment can be visualized as a three-dimensional world (e. g., Brown 2010) in which the modeler acts as an avatar conducting interviews with stakeholders and, building on that, creating a three-dimensional conceptual model.

Purely text-based approaches are less represented in the final sample with three publications (Grillo and Fortes 2014a,b; King et al. 2004). Both the input and the navigation in the conceptual model takes place via a text-based user interface. Text-based modeling tools are primarily intended to support users with visual impairment in constructing conceptual models by voice input

User Interface	Publications	Sum
GUI	Barbosa et al. (2014), Bogdan et al. (2012), Bork and Sinz (2011, 2013), Dean et al. (1995, 1998, 1996), Derntl et al. (2014, 2015), Dudley (1989), Effinger (2011), El Dammagh and De Troyer (2011), Fellmann et al. (2013), Fleischmann and Schmidt (2014), Gogolla et al. (1999), Hornung et al. (2008), Huang et al. (2011), Lee et al. (2000), Nicolaescu et al. (2013, 2017), Pendergast et al. (1999), Penichet et al. (2008), Radfelder and Gogolla (2000), Ram and Ramesh (1998), Safdar et al. (2015), Sapia et al. (2000), Schiele et al. (2015), and Thum et al. (2009)	28
NUI	Alpers et al. (2015, 2014), Alpers and Hellfeld (2016), Chen et al. (2008), Damm et al. (2000a,b), Döweling et al. (2013), Kammerer et al. (2015), Kolb (2015), Kolb et al. (2012, 2013), Kolfschoten et al. (2009a,b), Nolte et al. (2016, 2015), Nolte and Gulden (2017), Renger et al. (2008), Ritter et al. (2015), and Scholtz et al. (2015, 2013)	20
TUI	Ionita et al. (2015)	1
VR	Allisat et al. (2002), Betz et al. (2008), Brown (2010), Brown et al. (2011), Effinger (2013), Eichhorn et al. (2009, 2010), Krallmann et al. (1999), Poppe et al. (2013a,b), Steinfath et al. (1997), West et al. (2010), and Zang et al. (2004)	13
AR	Metzger et al. (2017) and Poppe et al. (2012)	2
Text-based	Grillo and Fortes (2014a,b) and King et al. (2004)	3
Non-specific	Becker et al. (2013), Fleischmann et al. (2014), Kohler and Kerkow (2008), Shitkova (2014), and Zuckerman and Gal-Oz (2013)	5

Table 2: UI categories as applied in final sample contributions.

and output via headset as well as text input and output via Braille keyboards.

In the non-specific category, five contributions were identified (Becker et al. 2013; Fleischmann and Schmidt 2014; Kohler and Kerkow 2008; Shitkova 2014; Zuckerman and Gal-Oz 2013). Two of the contributions present comparative analyses of TUI-based user interfaces with non-tangible user interfaces, especially GUI-based ones (Fleischmann and Schmidt 2014; Zuckerman and Gal-Oz 2013). Both studies highlight the advantages of the TUI-based user interface, especially in terms of user experience and user involvement. The remaining three contributions are overview articles (Becker et al. 2013; Kohler and Kerkow 2008; Shitkova 2014).

5.2 Design recommendations

We observe only very few explicit design recommendations in the final sample. Huang et al. (2011) point out that less experienced users, especially beginners in modeling, prefer symbol libraries, for instance, to create graphical symbols on the modeling canvas, to using the (partially hidden) function of context menus offering the same or extended functions. For model elements representing entity and relationship types in the Entity-Relationship Model, Huang et al. recommend to always provide a context menu for direct creation on the modeling canvas and to use graphical highlighting for labeling as well as for changing model elements. Besides, information on functionalities and guidance windows should be presented to users, but distractions should be avoided, e. g., caused by covering the modeling canvas (cf. Huang et al. 2011, p. 551).

Steinfath et al. (1997) provide design recommendations for VR-based modeling tools. In a three-dimensional representation of conceptual models, they recommend to avoid the concealment of image areas and the waste of display space (Steinfath et al. 1997, p. 137f). More precisely, the integration of functionalities for highlighting model areas of interest by filtering model elements on the canvas according to the "Fish-Eye-View" (cf. Steinfath et al. 1997, p. 137) is proposed to overcome this challenge: The area of interest can be displayed in full size and detail, while other areas are displayed smaller with increasing distance from the area of interest.

For NUI-based modeling tools, the limited screen width is discussed as a limitation that causes users to perceive the user interface as too overloaded and too challenging to use (e. g. Kolb et al. 2012). Hence, it is recommended to use tablets and multi-touch tables for capturing and modeling business processes while interviewing process participants (e. g., Kolb et al. 2012, p. 280). On the other hand, multi-touch devices with larger screens, in turn, can be used to support collaborative modeling. However, *traditional* process modeling tools have not been designed to run on multi-touch devices and, thus, do not take their specific properties (e. g., small screen size) and interaction paradigms (e. g., gesture-based interaction) into account (cf. Kolb et al. 2012, p. 280). Displaying menus and toolbars requires space on the screen, which can be limited on devices with small screens (e. g., smartphones). Hence, Kolb et al. (2012, p. 280) recommend that menu-based interaction should primarily be used for multi-touch applications running on larger screens.

Software ergonomics standards, e. g., ISO 9241, are only considered in seven contributions (Becker et al. 2013; El Dammagh and De Troyer 2011; Kammerer et al. 2015; Kohler and Kerkow 2008; Scholtz et al. 2015; Shitkova 2014). Furthermore, design specifics of modeling tools and implemented modeling methods are only rarely discussed in the light of recommendations provided in these standards, and recommendations based on software ergonomics standards do not specifically support the design of modeling tools and, in particular, supportive modeling functions. Hence, specific recommendations on functions for facilitating conceptual modeling based on software ergonomics standards are missing. The remaining 65 contributions neither refer to standards for modeling tool development nor use them as a (terminological) foundation.

6 Paths for future research

Thirty years of research, from 1980 to 2017, has led to a mere 72 publication on user interface design for modeling tools—a surprisingly low number in light of the importance of modeling tools for practicing modelers. In a general view, this finding suggests to further address modeling tools and their user interfaces in research in various fields from conceptual modeling research to human-computer interaction research—with further, more specific paths for future research suggested by the findings of this study (see Fig. 5 for a summary). We discuss these paths along our analysis dimensions.

6.1 User interfaces

It is not surprising that GUI-based user interfaces are suggested for conceptual modeling tools in the majority of analyzed contributions. Text-based, AR-based and TUI-based modeling tools are only discussed in a few contributions, while NUI- and VR-based modeling tools are also in the focus of the analyzed publications, especially in recent years. This development can be seen in the context of the increasing development and diffusion of more powerful hardware, e. g., for the display of complex virtual environments, touch-sensitive devices, e. g., tablets and electronic boards (e. g., Kolb 2015; Kolb et al. 2013) and semi-transparent computer-controlled glasses (e. g. Berkemeier et al. 2019; Metzger et al. 2017). For NUI-based modeling tools, intuitive handling by natural gestures is stressed in view of better access to the modeling tool (e. g., Kolb et al. 2013). The use of avatars within VR-based modeling tools and the associated high intensity of user immersion has the potential to have positive effects on collaboration (e. g., Brown et al. 2011). Concerning both NUI- and VR-based approaches, it is striking that—although the use of these technologies is

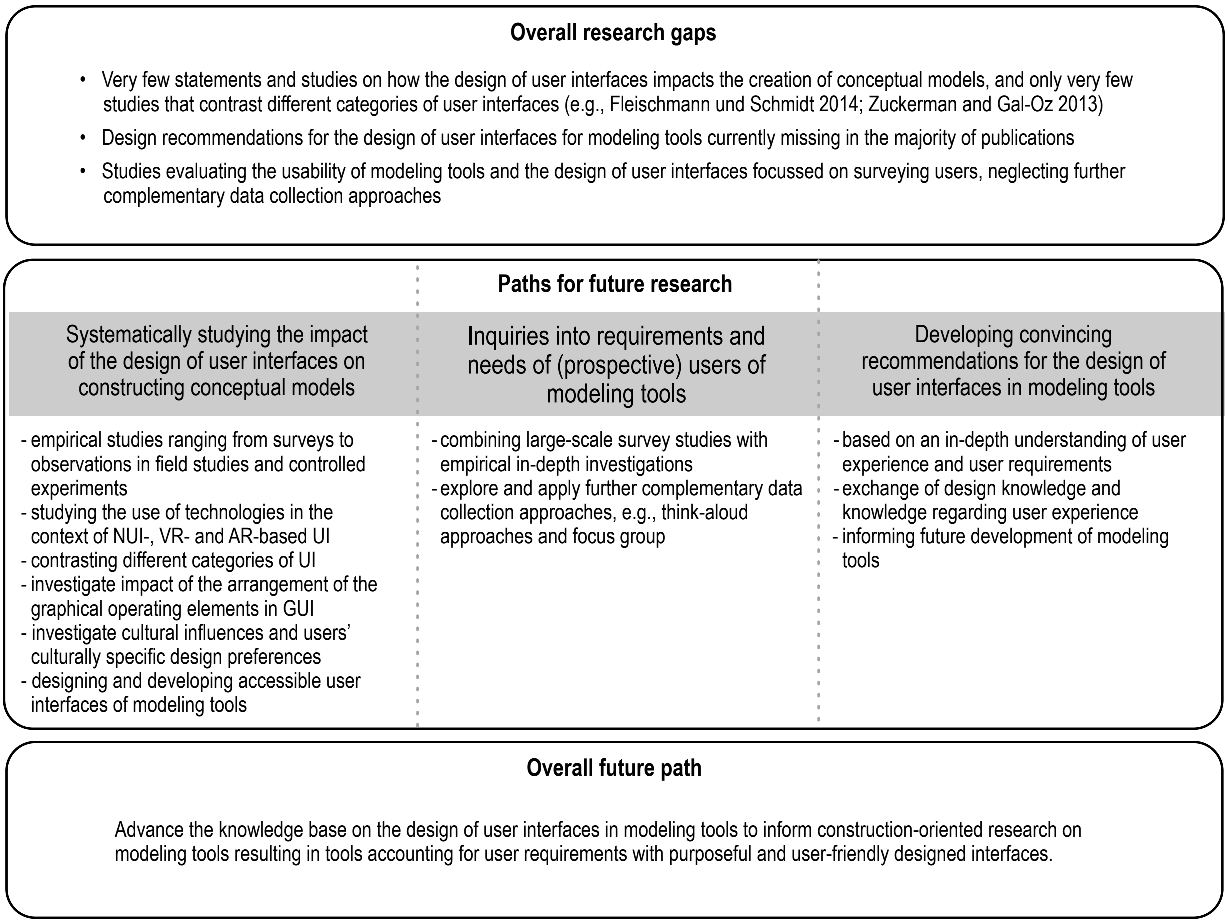

Figure 5: Paths for future research on the design of user interfaces in modeling tools.

widely proposed—the question of how these technologies can adequately support the creation of conceptual models has so far received only very little attention (e. g., Brown et al. 2011; Kolb et al. 2012).

Overall, one major research gap emerges from analyzing user interfaces applied in modeling tools: There are very few studies on how the design of user interfaces can support the creation of conceptual models by sensible and supportive alignment of elements and support functionalities as, for example, syntax checking. In addition, insights into differences among user interfaces with respect to user perception, user involvement, and modeling outcome are only very limited (e. g., Fleischmann and Schmidt 2014; Zuckerman and Gal-Oz 2013). A potential path for future research, hence, lies in systematically investigating the impact of the design of user interfaces in modeling tools on modeling processes by users in empirical studies ranging from observations in field studies to controlled experiments: More precisely, studies could focus on how the alignment of user interface elements (e. g., symbol palette, metaphors) and supportive functions influence modeling processes of tool users and the created conceptual model as modeling outcome. In the light of our observation that most GUI modeling tools use a notation symbol palette on the left side, it remains an open question whether this alignment strategy is superior. Surprisingly, the contributions in our final sample do not discuss alignment aspects of user interface elements. Hence, we deem studies relevant that investigate how the design and alignment of GUI elements influence user perception, experience and comfort, which is essential for the usability of a tool (e. g., Davis 1989)—especially in view of the widespread use of GUI in modeling tools. Insights from such studies contribute to a knowledge base for designing purposeful user interfaces of modeling tools and inform future construction-oriented research on modeling tools. Widget-based modeling tools already allow users to adjust the orientation and location of the user interface elements to their own needs (e. g., Nicolaescu et al. 2017), but these approaches require discussion with regard to cognitive overload of the users (e. g., Bera 2012). Hence, future research should consider cognitive overload with respect to user interface design for modeling tools.

Despite the importance of cultural influences on user interfaces (e. g. Marcus 2002), this topic is not addressed in the analyzed contributions on user interfaces of modeling tools. People from different cultures may use user interfaces in different ways, prefer different alignments, and have different expectations and patterns in behavior (cf. Marcus and Baumgartner 2004, p. 252). So far, research on this topic demands that user interfaces have to be adapted to the needs of different locales to provide a better user experience and comfort (Evers and Day 1997). Consequently, further research on cultural influences and users' culturally specific design preferences promises to lead to a more predictable and understandable overview of behavioral consequences for the design of modeling tools.

Accessible user interfaces of modeling tools for users with disabilities (e. g., visually impaired users) are only suggested and discussed very rarely in the final sample. We count only one approach suggesting a text-based user interface to construct graphical models based on textual input from a braille keyboard (Grillo and Fortes 2014a,b; King et al. 2004). In the context of distance teaching and learning, this aspect becomes particularly important with respect to achieving the goals of openness, equality and accessibility in education (e. g., Akcil 2018). A further fruitful path for future research thus lies on designing, developing and discussing appropriate accessible user interfaces of modeling tools.

Although several contributions suggest VR- and AR-based approaches, it is only rarely discussed how technologies such as VR and AR can support conceptual modeling through integrated tool support and modeling environments. We identified two recent studies addressing TUI, NUI and GUI by comparing users preferences for these user interfaces (Fleischmann and Schmidt 2014; Zuckerman and Gal-Oz 2013). Further studies could address how exactly the use of technologies in the context of TUI-, NUI-, VR- and AR-based user interfaces supports the construction of conceptual models (e. g. Fleischmann and Schmidt 2014). Hence, another fruitful path for future research lies in systematizing, contrasting, and comparing different types of user interfaces in modeling tools to achieve an in-depth understanding of the strengths and weaknesses of different user interfaces.

6.2 Design recommendations

Analyzing recommendations for the design of user interfaces for modeling tools, a further major research gap emerges: Such design recommendations and standards on software ergonomics as well as the design of software tools are discussed only marginally in the final sample—although, for example, recommendations for the arrangement of pallets and graphical elements in software tools are available (see the ISO 9241 series of standards). We consider this observation to be important in two main respects: The exchange of design knowledge and knowledge regarding user experience is crucial for the progress of tool research. However, design recommendations are currently missing in the majority of publications (possibly design recommendations are communicated in other forms, e. g., verbally, which are not investigated here). For the exchange between research and its application practice, tool research, on the one hand, faces the challenge that the requirements of prospective users are not known. On the other hand, a lack of well-founded design recommendations leads to developers in practice ignoring research results. It promotes that conceptual modeling tools and support functions tend to irritate rather than support, reduce rather than increase productivity because they do not meet user requirements (see Cooper et al. 2014).

Hence, the present analysis suggests future research aimed at the development of convincingly justified recommendations for the design of user interfaces in modeling tools. As a first step toward design recommendations, gaining an in-depth understanding of requirements of (prospective) users appears as a fruitful avenue for future research: Conducting studies surveying (prospective) users aimed at a structuring overview could be combined with in-depth empirical studies, e. g., applying observations and interviews for data generation, that contribute to a detailed understanding of user experience with user interfaces in modeling tools. Resulting design recommendations are expected to inform the development of modeling tools and, hence, to benefit prospective users with providing user interfaces and support functions for conceptual modeling that take into account user experience and thus user requirements.

6.3 Emerging research themes

Scrutinizing prior work on user interface design of modeling tools leads us to identify three emerging research themes: (1) supportive approaches for user interface design and development, (2) general aspects of evaluation approaches & procedures, and, in particular, (3) data collection for evaluation.

Surprisingly, (1) applying supportive approaches for designing and developing user interfaces of modeling tools, e. g., regarding how modeling tool support can be located and with respect to the alignment of graphical metaphors (e. g., Huang et al. 2011), has only received very little attention. It is remarkable that applying approaches such as paper-based prototypes, video-prototypes, or mock-ups (Mackay et al. 2000), can only be observed as emerging phenomenon addressed in two more recent contributions (Bogdan et al. 2012; Huang et al. 2011). Although related research on paper-based prototypes shows that traditional computer-based prototypes and paper-based prototypes lead to almost the same quantity and quality of critical user statements, subjects tend to prefer computer prototypes (e. g., Sefelin et al. 2003). Nevertheless, we consider alternative approaches as, e. g., paper-based prototypes or mock-ups, as helpful, in particular, if prototyping tools do not support the components and ideas that should be demonstrated—allowing prospective users to be involved in this development step. Furthermore, these approaches can provide a basis for discussion, for example, on the arrangement of graphical elements, metaphors and integrated tool support in the (graphical) user interface, e. g., by including (specific) requirements of prospective users—which is mentioned in only one contribution in the analyzed sample (cf. Huang et al. 2011, p. 544).

Furthermore, we observed that (2) primarily user-centered evaluation procedures are recommended for assessing the suitability and usability of a modeling tool, by (3) applying different data collection approaches, for example questionnaires complemented with video observations (e. g. Damm et al. 2000b), which are proposed as an appropriate basis for evaluation (e. g., Hornung et al. 2008; Safdar et al. 2015; Schiele et al. 2015). It is noteworthy that access to users already takes place via various and complementary data collection procedures, e. g., by surveying and interviewing subjects (e. g., Hornung et al. 2008). However, data collection approaches such as think-aloud approaches asking users to speak out loud every aspect of their reasoning (Ericsson and Simon 1980, 1993) or *focus groups* (e. g., Ionita et al. 2015) are surprisingly rarely applied for evaluation purposes. We count only two contributions applying a think-aloud approach (Huang et al. 2011; Kolb 2015). Indeed, think-aloud approaches offer the opportunity to collect very detailed insights into modelers reasoning and cognitive processes, and is considered in the context of usability research and evaluation (e. g., Nielsen 1999) as well as (second) language acquisition studies (e. g., Bowles 2010)—"generally recognized as major sources of data on subjects' cognitive processes in specific tasks" (Ericsson and Simon 1993, p. xi).

Altogether, we observed that most of the studies evaluating the usability of modeling tools and the design of their user interfaces focus on surveying users either before or after using a modeling tool—the combination of both approaches is only used to a limited extent (e. g., Huang et al. 2011). Further data collection approaches, such as think-aloud (Ericsson and Simon 1980) or focus groups, are only identified as a more recent and nascent phenomenon in modeling tool research, although they promise further insights into prospective users' reasoning about a modeling tools and interacting with the (graphical) user interface (e. g., Huang et al. 2011; Kolb 2015). In addition, approaches taking complementary perspectives on the research object promise deeper and more detailed insights into users' reasoning—offering the opportunity to better understand how users interact with modeling tools and provided tool support, what makes the user interface easy to use, and how users can be supported by targeted tool functionalities. Hence, a fruitful research direction lies in exploring and applying further data collection approaches as, for example, focus groups and think-aloud approaches to enrich user-centered evaluations within construction-oriented research on modeling tools. Considering complementary perspectives promises to facilitate meeting user requirements and to contribute to purposeful designed user interfaces in modeling tools.

7 Conclusion

The review at hand provides a structuring overview of the current state of research on the design of modeling tools with a focus on the design of user interfaces by compiling and analyzing 72 publications published between 1980 and 2017. To achieve an intentionally comprehensive overview, the literature search considered literature in the fields of business informatics, applied computer science and, in particular, HCI combining different search strategies. The literature analysis suggests three major opportunities for a future research agenda on the design of modeling tools: (1) Systematically studying the impact of the design of user interfaces and, in particular, the use of technologies in the context of VR and AR on construction processes of conceptual models by users—in empirical studies ranging from observations in field studies to controlled experiments. (2) Inquiries into requirements and needs of (prospective) users of modeling tools, for example, by combining large-scale survey studies with in-depth empirical investigations that explore and apply further complementary data collection approaches, e. g., think-aloud approaches and focus groups. Findings from such investigations contribute to a knowledge base for designing purposeful user interfaces for modeling tools. (3) Systematizing, collecting, and developing further convincing and meaningful recommendations for the design of user interfaces in modeling tools based on an in-depth understanding of user experience and user needs. Such a knowledge base can support the exchange of design knowledge, knowledge about user experience, and recommendations for user interfaces, which is crucial for the progress of tool research, for instance, with regard to the general ease-of-use design goal of most modeling tools. Research efforts following the suggested research agenda advance our knowledge on the design of user interfaces in modeling tools and to inform construction-oriented research on modeling tools resulting in tools accounting for user requirements with purposeful and user-friendly designed interfaces.

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A Appendix—Final sample

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