Exploring and Characterizing Ad-hoc Requirements - A Case Study at a Large-scale Systems Provider

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Abstract. [Context and motivation] In addition to precisely representing requirements in specification documents and requirements management tools, practitioners use quick-and-dirty representations that are not compliant with academic guidelines or industry best practice recommendations. This includes drafted and informal representations in meeting notes, e-mails, and presentation slides. Sometimes, however, these representations may serve as a *replacement* for precise and officially specified requirements. [Question/problem] Although we presume that these requirements representations exist in most projects, the scientific community lacks evidence and characterization of these requirements. Studying these requirements is crucial because their use may pose severe challenges in later phases. [Principal ideas and results] We conduct an in-depth case study at a large-scale software and mechatronic systems provider. We use multi-method research, including a survey, interviews, and an analysis of processes and artifacts. We (1) explore instances and context of these requirements, (2) conceptualize the observations, and (3) define an *ad-hoc requirement* as one that is written, stored, or communicated in a suitable-for-the-moment manner. [Contribution] We position ad-hoc requirements (*AhR*) in the RE landscape and offer researchers a category of industry RE situations and challenges worth investigating.

Keywords: Requirements, Ad-hoc requirements, Industry research

1 Introduction

Besides accurately written specifications, practitioners sometimes use drafted, informal, and incomplete representations of requirements [10], like meeting minutes, e-mails, presentations, document annotations and comments, and personal notes. These are used not only as interim reminders for further specification activities, but can also be shared with others as a handover artifact (see the process in [18] and Fig. 2).

Although the Requirements Engineering (RE) community shows awareness of this concept by using terms such as "informal" or "raw" [2, 3, 9, 10, 12], there is no unified characterization that, in addition to defining them, provides examples from industry, and that analyzes the reasons for their existence.

We present an empirical investigation, through which we identified and characterized a particular category of these requirements that we call *ad-hoc requirements (AhR)*.

The term *ad-hoc*[1] underlines that these requirements are created out of individual needs in a given situation based on the skills and preferences of their writers. Our study is motivated by the fact that the suitable-for-the-moment nature may be sub-optimal for later development phases wherein requirements must be broken down per sub-system, implemented, validated, and evolved.

This research is enabled by a large-scale case study at a global provider of intralogistics automation solutions (LAS). The solutions include robots, transport and storage systems, different kinds of intralogistics software like machine controlling software, and Warehouse Management Systems (WMS). Customer solutions are provided as an orchestration of existing products, configuration, and individualization.

This paper is part of an ongoing research project that studies RE practices at multi-component solution providers like our case company. In that embodying research, the results from process analysis and a survey provided strong evidence that practitioners concerned with RE tasks experience challenges based on using "informal" requirements as presented in meeting notes, e-mails, or presentations. This triggered the present study, which explores the occurrence of *AhR* in a case study using multi-method research. We address the following research questions:

- RQ1: What are the characteristics of ad-hoc requirements?
- RQ2: Why do ad-hoc requirements exist?
- RQ3: What kind of information is covered in ad-hoc requirements?

Our main contribution is *an empirical characterization of an intuitively existing phenomenon: the use of AhR*. Through data from our case study, we address the RQ1-RQ3 and provide a definition of AhR for the community to use.

We first present our definition of AhR in Sect. 2 for readability. We describe the research methods in Sect. 3, then present observations and data insights in Sect. 4. We discuss threats to validity in Sect. 5 and conclude in Sect. 6.

2 Ad-hoc requirements

We introduce our definition of ad-hoc requirements. Although this is derived from our conducted research (Sect. 4), we present the definition here first to improve readability.

Brief definition: An ad-hoc requirement is a requirement that is at least *written*, *stored*, or *communicated* in a manner inconsistent with RE guidelines, motivated by a focus on *immediate suitability* rather than by long-term effects.

Extended definition: A requirement R is said to be ad-hoc if and only if at least one of the following three properties hold:

(1) *R* is *written* in a quick and easy way, which the author considered suitable at the moment of writing, as opposed to following requirements quality guidelines such as the use of templates and unambiguous language.

[1] Merriam-Webster: ad-hoc [adj] "formed or used for specific or immediate problems or needs" and [adv] "for the particular end or case at hand without consideration of wider application".

(2) *R* is *stored* based on the author's preferences and the convenience of accessing the tool or storage platform, rather than opting for storage in a platform that supports traceability and long-term shared accessibility.
(3) *R* is *communicated* in an early status, either during refinement or before agreement, as opposed to sharing approved requirements.

An orthogonal and complementary class of requirements are those that are *ad-hoc appearing*, i.e., created outside the expected or prescribed process (e.g., a requirement communicated during an iteration after the requirements for that iteration had been frozen). These are ad-hoc requirements only if one of the criteria (1), (2), or (3) are met.

3 Research approach

This section outlines the multi-method research approach we used to investigate the nature of AhR in our case study. Data collection took place in 2023 and 2024. We use the methodological terminology according to [1]. Considering the complexity of our methods, we provide only an overview here, and we refer the reader to our online appendix for additional details and materials [18].

Terminology. In the first (exploratory) research phase, we used words like informal, drafted, documented in e-mails and meeting notes, incomplete, and not fully defined in the communication with the participants. In this paper, this is represented by the term *informal requirement*, which denotes requirements that are not yet fully refined or not compliant with requirement quality standards. Based on our initial results, in the second (descriptive) phase, we defined the term *ad-hoc requirement* as per Sect. 2.

3.1 Research design

This case study employs multi-method research, illustrated in Fig. 1, to address the research questions RQ1-RQ3, focusing on an in-depth analysis within a single company. This study is part of a broader *evaluative research* – see (1) in Fig. 1 – employing (A) process analysis, and (B) a mainly qualitative survey. The research conducted in this paper (C-G in Fig. 1) derives from the findings in (A) and (B) related to handover of requirements and perceived challenges by using *informal requirements*.

With a focus on *informal requirements*, we conduct *exploratory research* – see (3) in Fig. 1 – through (C) qualitative data analysis (hybrid coding) of survey data from (B) and (D) manual artifact analysis (inductive coding) of a first set of requirements artifacts provided as examples for *informal requirements* by company employees. A consolidation of these results led us to the conception of the term *ad-hoc requirement*.

The rest of the research is of a *descriptive nature* – see (4) in Fig. 1 – and it focuses on *AhR* via data analysis of the interviews (hybrid coding) and (G) detailed manual artifact analysis (hybrid coding) with an extended set of requirement artifacts. These last three steps lead to the characterization of AhR presented here.

Throughout the paper, we refer to the research methods in Fig. 1 using the letters A to G. Details about the designs, including the used questionnaire, guidelines, and codebook, are accessible at [18]. We used the methodological terminology according to [1].

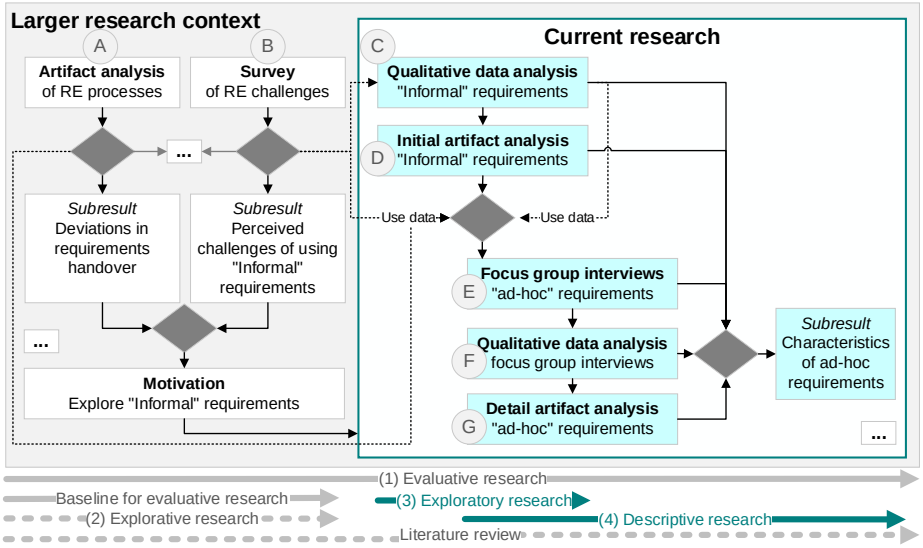

Fig. 1. Overview and sequencing of the used research methods.

3.2 Sampling

Company. The case study company was selected based on opportunistic sampling and has over 3,000 employees in more than 20 countries across 6 continents. The observation subject is a global provider of highly adjustable intraLogistics Automation Systems (LASs) based on mechatronic and software sub-systems.

The development, configuration, and customization of a LAS is done along a large-scale RE process (see Fig. 2 for a simplified illustration) that includes twelve levels (L1-L12) in which requirements are created, refined, distributed to sub-systems, and communicated across various levels. These requirements may relate to strategic directions, the standard system, sub-systems including mechatronic and software, or individual customer project setups. A LAS possesses many configuration options and customizations to cope with the diversity of the customer's regional regulations, handled products, included sub-systems, and interfaced software systems.

RE population. Along this process, we identified 738 employees as RE population with either (i) formally assigned responsibility for RE (266) or (ii) software development or test responsibility and perceived RE responsibility (472). We assigned each member of the population according to their area of activities to a level of the process model as groups L1-L12 (see Fig. 2). We postponed a systematic identification of the mechanical engineering RE population (L11) due to prioritization and included them occasionally by 21 employees. L11 is not included in the RE population of 738.

Survey. For the survey (B), we invited 266 members of the formally assigned RE responsible groups (census sampling). From the groups with perceived RE responsibility, we conducted expert sampling supported by group managers and invited a diverse sample of 155 employees. Inclusion criteria contained different experience levels,

global distribution, and current project workload. We invited 421 employees to participate in the survey and received 187 valid responses. We omit L11 in the survey because of their focus on mechatronic engineering for cranes, robots, and storage systems.

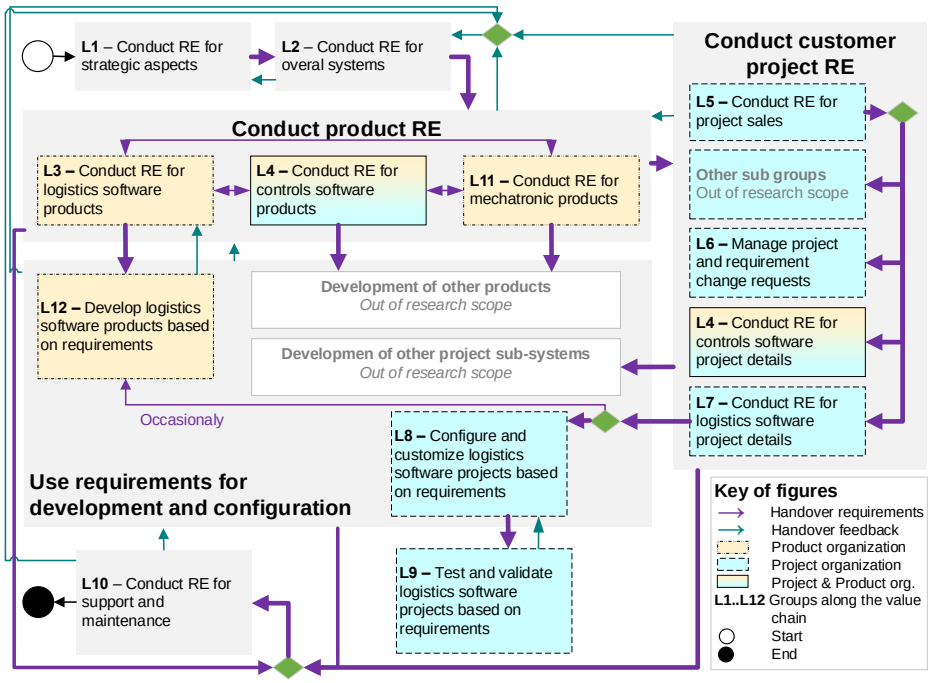

Fig. 2. Simplified RE process including development.

Artifacts I. For the initial artifact analysis (D), the first author identified two experienced representatives per group L1-L12 from the respondents to the survey (for L11 by convenience sampling). These experts were asked to provide examples of artifacts they would label as *informal requirements* (purposive sampling). Six of the contacted 24 employees provided a total of 28 artifacts with extensive sub-artifacts like images, files, and e-mails. The artifacts cover the involvement of all groups L1-L12. The artifacts were provided voluntarily and with the consent of the involved people.

Focus Groups. For the focus groups (E), expert sampling was done per group L1-L12 in collaboration with the group managers (for L11, by convenience sampling). Sampling criteria included global distribution, different experience levels, coverage of different roles, and reduction of hierarchical influences in a focus group. Interviews for L4, L5, L8, and L12 are not included in this publication. For the other groups, we invited 67 employees; 54 joined one of the 22 focus group interviews.

Artifacts II. For the detailed artifact analysis (G), we asked all focus group interview participants for examples of artifacts containing requirements they would label as *ad-hoc or informal* (purposive sampling). We received 71 artifacts, which we analyzed together with the 28 artifacts used in the initial artifact analysis using a more extensive

coding scheme. These 99 artifacts included extensive sub-artifacts like files, links to the requirements management tool, images, and e-mails.

The online appendix [18] provides an overview of the population and used samples.

4 Data analysis

We present details about the collected data, their analysis, triangulation, and how they contribute to answering our RQs. Note that AhR are only a subset of used requirements in the case study company. Due to confidentiality, we cannot share the artifacts we analyzed, but we provide additional information in the appendix [18].

We present the results starting with the relevance of researching AhR and provide the other data in the sequence of the research question from RQ1 to RQ3. We highlight triangulation aspects in this sequence.

4.1 Ad-hoc requirements experienced as a challenge

Our process analysis (A) revealed deviations related to requirement handover processes, and the survey results (B) showed challenges related to requirements solely documented in meeting notes, e-mails, or presentations (61%, n=187) and the use of different tools to work with requirements (49%, n=187). This strong evidence for the relevance of our research about AhR led us to include questions in the focus group interviews (E) to validate the survey results. Asked about the most resonant challenges, only 9% (n=54) named documented in meeting notes, e-mails, or presentations, and only 6% (n=54) selected use of different tools. Still, the participants described that requirements were stored in ad-hoc written meeting minutes (37%, n=54) and shared ad-hoc in e-mails (81%, n=54) or PowerPoint (70%, n=54).

4.2 RQ1: What are the characteristics of ad-hoc requirements?

We present our findings according to our research method: (i) the exploratory research regarding informal requirements – (3) in Fig. 1 –, leading to a conceptualization of AhR; and (ii) the descriptive research on the characteristics of AhR, see (4) in Fig. 1. The chain of evidence is in our online appendix [18].

Exploratory research. By inductive coding on the survey (C) and the initial artifacts (D), we identified the codes illustrated in a clustered view in Fig. 3.

From the survey (C), we analyzed 193 responses to question #15 about *additional experienced requirements-related challenges* and #16: *open feedback from the survey* (see [18]). Within these, we coded 30 segments from 29 participants as related to informal requirements. We used inductive coding of 28 artifacts (including 102 e-mails, 11 Polarion items, 6 spreadsheets, and 38 other sub-artifacts) for the artifact analysis (D). Even though provided by only 6 participants, the artifacts cover a wide range of writers distributed worldwide and assigned to all groups besides L9 and L10 (see [18]).

The high-level clusters shown in Fig. 3 are *requirements writing*, *communication and handover*, and *requirements storing*. We conceptualized the codebook for the following research phase – (4) in Fig. 1 – based on these codes and elements from models

for requirements evolution [12, 13, 16] to analyze which attributes of AhR change over time. The complete codebook, which we used in the descriptive phase of the research, is available in the online appendix [18].

At this stage, we identified the need for a term for the requirements under study. Existing terms like *drafted* or *informal* requirements were found to be vague and already used with different meanings. Thus, we introduced the term *ad-hoc requirement*.

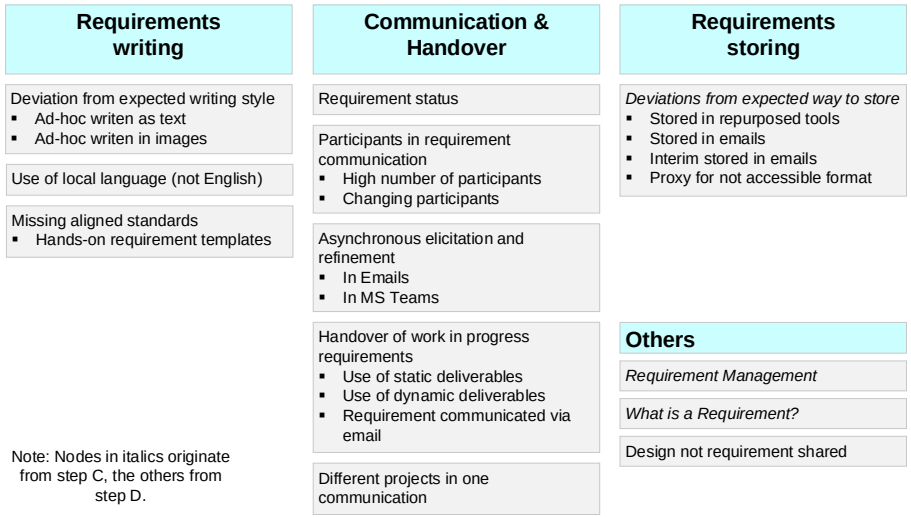

Fig. 3. Clustered view of codes related to RQ1 in the exploratory research phase.

Descriptive research. To describe the characteristics of AhR, we used qualitative data analysis (hybrid coding) on focus group interviews with 54 participants (E&F) and on 99 requirements artifacts (G). We focused on the artifacts that showed deviation from company guidelines. We present the observations from the interviews (E&F) and the detailed artifact analysis (G), enriched by examples from steps (C&D). To highlight triangulation aspects, we present the observations based on the following pattern {EF(number of interviews with code instance), G(code instances|number of artifacts with code instance), D(number of artifacts)}.Whenever quoted content contained sensitive data, we replaced the data by generic terms, indicate by <general term>.

General aspects. Our data reveals that the most frequent *status* of AhR is *candidate* {EF(6), G(314|45)} (thus, not yet a settled requirement), followed by *agreed* {EF(5), G(225|23)}; we also found evidence for its status as validated {EF(3), G(17|3)}, and *refused* {/, G(14|7)}.

The *context* addressed with the requirements depends on the study object. In our LAS case, there was no major difference between *product* {EF(2), G(50|18)}, which is related to new products and product enhancement, and *project* {EF(2), G(46|26)}, denoting the realization of customer projects. From a system context perspective, WMS *software* {EF(6), G(126|39)}, and *mechatronic* {EF(6), G(77|22)} were frequently addressed, less the *overall system* {EF(3), G(22|10)}, and only in isolated cases the *mechatronic-controls software* {/, G(10|2)}.

Requirements writing. The most used notation for representing AhR is also *ad-hoc* {EF(9), G(598|63), D(41)}, which relates to using pragmatic representations instead of using templates or following guidelines. This is illustrated by the following requirements: (1) "*optimize <solution> creation / optimize layer pick/stacker planning → this is a <software> code change*", (2) "*improve <warehouse area> picking speed → this topic can't be completely fixed on software side.*" Some AhR were *not documented* {EF(8), G(5|1)} in cases where the provided notation made the requirement intangible, e.g., a personal note close to a list of AhR "*list the others [requirements] and send to <name>*". Some were labeled as *formally written* {EF(4); G(13|15)}, e.g., a software-relevant logistics flow "*After picking is completed at the picking stations, the totes will be transported to a weight check on the conveyor.*", which was persisted in OneNote as a reminder for further RE activities.

For *ad-hoc written* requirements, we found *image-based representations* {/, G(67|14), D(19)} as well as *textual representations* {/, G(531|49)}. One example is a text embedded in an image on the left side of Fig. 4, translated to "*Light tower at <Robot> cell function – not used. Shall be used if package arrived at replenishment.*".

AhR can include *images* that, without expressing a requirement, support understanding {EF(1), G(192|52), D(21)}; for example, LAS-specific material flow diagrams, warehouse layouts, warning signs, electronic schematic, and general software-related images as screen shoots, class diagrams, software process models. The LAS-specific images are valuable input for the software teams, as a domain expert can extract many implicit requirements from these images.

Local non-English languages {G(84|19), D(5)} are sometimes used for written requirements and in requirements discussions within an English context. An example of a German annotation in an English artifact is on the left side of Fig. 4.

Fig. 4. Examples of an in image textual requirement (left) and a requirement template (right).

Participants reported *deviations from standards* {C(6)} and multiple formats within the company due to its size. Sometimes, *hands-on requirements templates* are embedded in office tools {C(6), G(6|6)}; the right part in Fig. 4 shows an example of a PowerPoint-based requirements template.

AhR are used in *repurposed tools and formats* {EF(16), G(100|44), D(13)} like *e-mail* {EF(11), G(100|89), D(85)}, *spreadsheets* {EF(11), G(7|7)}, *presentation without templates* {EF(7), G(16|14)}, *OneNote* {EF(4), G(10|5)}, and *MS Teams chats* {EF(8),

G(16|3)}. We found evidence for their use in *group internal official tools* {EF(9), G(27|14)}, like office tools with template setup including *Excel* {EF(5), G(12|5)}, *PowerPoint* {EF(5), G(4|2)}, and *Word* {EF(4), G(2|2)} templates (see right image of Fig. 4). AhR are also used in *global official tools* {EF(13), G(27|25)}, like the requirements management tool *Polarion* {E(12), G(18|16)}. Here, we see a similarity with other WMS providers that use a diverse RE tooling including office tools extensively [17].

Accessibility addresses access rights, infrastructure to support required file formats, and usability. Accessibility restriction for data security and related aspects is a must-have. AhR were stored with access for *named employees* {EF(8), G(70|45)}, only accessible *for the author* {EF(5), G(18|7)}, access for *named groups* {/, G(16|9)}, limited by *infrastructure accessibility* boundaries {EF(2), G(5|4)}, access for *all employees* {EF(1), G(3|2)}, and access for *named external* {EF(2), G(2|2)}. Limited accessibility sometimes caused AhR as a workaround by providing static exports after a notification like "*we do not have any software that we can use to export <file type>*" is received.

Requirement documents and tools are used to persist AhR. Examples are quickly evolving changing AhR in *e-mail* and *Polarion* communication.

Communication and handover. AhR were used by all groups L1-L12, and bi-directional collaboration between different groups was visible in the artifact data (see [18]). We identified a maximum of 16 participants, a minimum of 2, and a median of 5 participants involved in an artifact and artifact-related communication in G. During communication, the *involved participants in written requirement communication may change* {/, G(96|9), D(96)} by adding or removing participants or branching discussions. The aspects of information exchange and storage are closely related to the quick evolution of AhR, as the fast pace and constant changes may sometimes lead to sharing a static copy for efficiency reasons.

Based on these artifacts, *communication* was extensively done via *e-mail*{EF(19), G(108|100), D(102)}, either representing (i) *asynchronous communication about requirements* {/, G(115|38), D(94)} or (ii) *notification* {EF(1), G(9|7)} to inform about the creation or change of requirements in Polarion: "*I will send you […] the link to the live document in <Polarion ID>*". Communication is also done in *Polarion* {EF(65|2), G(16|9)}, for *conducting asynchronous refinement discussions of requirements* {EF(4), G(3|3)}. The communication used in e-mails and Polarion resembles oral elicitation and refinement processes for requirements similar to examples from requirements elicitation transcripts. *PowerPoint presentations* {EF(8), G(12|12)} represent, in some cases, requirements communication as either (i) used to collaboratively elicit, interim document, refine, and share requirements or (ii) to inform others about the here documented requirements in combination with a meeting. Similarly, *MS Teams Chats* are used to elicit or refine requirements in an asynchronous manner {/, G(9|7), D(1)}. An example of an asynchronous written elicitation is the extensive e-mail conversation between participants from different continents refining and agreeing on requirements.

Sharing was extensively done for requirements in the status *candidate* {/, G(217|39)}. Either (i) requirements are shared for collaborative refinement, or (ii) work-in-progress requirements are shared for further use in the receiving group. We found evidence that *static versions* {/, G(234|52), D(48)} of dynamic changing requirements were submitted to other teams and used for breakdown and realization on their

level. Examples are *e-mail branches* from refinement communications, or *PDF exports*. Some even argued that the shared PDF version is going to change: *"[…] here the specification for the new concept of the <topic>. In the attachment you will find a PDF-Version […] [the] document is a living document […].*"

Finally, requirements for *different projects* {/, G(18|18), D(1)} may be discussed in the same written communication flow, for example: "*For the files, I have now saved [...] for both <project A> and <project B> […]*".

4.3 RQ2: Why do ad-hoc requirements exist?

From the focus group interviews (E&F), we collected reasons for the existence of AhR. We coded the interview material (record, notes) from 54 participants and 22 interviews. The core reasons conducted are illustrated in Table 1. In the following, we use the following annotation (Code | Interview).

All interviewed groups mentioned *complex RE processes* as a reason for AhR. Highlighting that occasional *bypassing of process steps* (6|5) is done with the *desire to be faster* (5|4). Participants reported *complex stakeholder setups* as a reason, because multiple perspectives need to be included and aligned in large setups. To achieve such alignment, early sharing of AhR is experienced. *Complex documentation needs* were named by all groups but L11. The detailed feedback indicates that participants introduce additional documentation steps to *make work easier* (7|4). In one focus group, participants illustrated the following situation: "*The time interval between finishing [their part of the project] and getting requests [for clarification] might be month or even years*"[2], and they provided examples of personal notes that include requirements and tracking of changes that each of them created individually to make handling of future clarification requests easier, even though these data are available in the official setups. In addition to general deviations, some participants highlighted *missing traceability* (3|2), e.g., in case of RE activities at the customer site with limited IT access.

Time pressure and workload are reasons to quickly deliver results and to balance workload by using AhR. Some quotes highlight this: "*as they don't have the time to read the documentation […] it is more about summarizing […]"*[2] and "*I can quickly call and get a fast answer*"[2]. This requires prioritizing what is suitable for the moment over the long-term RE perspective. Regarding *oral sharing and refinement of requirements* (20|7), one participant said: "*we start with high-level requirements and need to break them down*" referring to AhR for *refinement from system to sub-systems* (15|5).

Highly customized system setups (6|3) described like "*progressing through different stages with the customer*", *geographical distance* (4|2) and location in different time zones, and *RE tool chain gaps* (21|10) are also named as reasons. Groups frequently working at the customer site mentioned their need of tools that are *accessible from different devices and usable in off- and on-line mode* (6|4) as a reason, leading to tools like OneNote for temporarily writing and storing requirements. Others named *parallel working* (2|2) on the same documents or work items as reasons for AhR. The *complexity*

[2] Translated to English by the first author.

and usability (3|3) of established requirements management tools and limited tool and *data access* (4|4) were other reasons.

Table 1. Reasons for AhR - The columns Cd and Int denote the frequency of this code and in how many interviews the code occurred. The checkmarks in L1-L11 indicate whether this reason was mentioned in focus groups for that process level.

Reason	Cd	Int	L1	L2	L3	L6	L7	L9	L11
Complex RE processes	46	14	✓	✓	✓	✓	✓	✓	✓
Complex documentation needs	33	13	✓	✓	✓	✓	✓	✓	-
Time pressure and workload	26	13	✓	✓	✓	✓	✓	✓	-
Complex stakeholder setup	26	10	✓	✓	✓	✓	✓	✓	-
RE tool chain gaps	23	11	✓	-	-	✓	✓	✓	-
Asynchronous written elicitation and refinement	23	10	-	✓	✓	✓	✓	✓	-
Oral sharing and refinement of requirements	20	7	✓	✓	-	✓	✓	✓	-
Alignment on requirements via meetings	19	7	✓	-	-	✓	-	-	-
Quickly evolving requirements	17	10	✓	✓	✓	✓	✓	✓	-
Missing skills/knowledge	14	9	✓	✓	✓	✓	-	✓	-
System complexity	14	9	✓	-	✓	✓	✓	✓	-
Make it suitable for different target groups	13	7	✓	✓	✓	✓	-	✓	✓
Easy and suitable for the moment	10	8	✓	✓	✓	✓	✓	-	-
Different understanding	10	5	-	-	-	✓	✓	✓	-
Others	9	7	✓	-	✓	✓	✓	-	-

Asynchronous written elicitation and refinement processes (23|10) are also mentioned. Distance and different times zones make it hard for participants to interact locally with some groups. Written communication is used and one participant stated: "*I directly write it as tracker, not to lose it*"[2]. This creates early AhR.

Alignment on requirements via meetings is another reason for introducing AhR (19|7). The participants expressed that long meetings require *reminders* (7|2) on the discussed topics, with AhR becoming notes in personal meeting notes. Additionally, each participant in a meeting has a different focus and expertise and the *meeting outcome* (1|1) is not the same for everyone. Personal notes with AhR can be helpful.

Other named reasons were grouped as *oral sharing and refinement of requirements* (20|7). Feedback includes reasons like *too busy to read* (7|5), so "*ad-hoc stories come relatively easily*"[2]. *Too complex to write* (3|3) is another sub-reason in this cluster, where the participants shared their impression as "*Often it is too complex to explain [requirements] in writing, so I prefer verbal [communication]*"[2]. Others highlighted *missing agreement* (9|5) by pointing to project situations where orally communicated information caused misunderstandings and AhR are used to overcome these.

Another cluster of reasons named by the participants are *quickly evolving requirements* (17|10), that is related to unclear customer requirements and sub-system dependency in case of changes; *missing skills/knowledge* (14|9) concerning intralogistics, the product, and RE; *system complexity* (14|9) including aspects about requirements

breakdown, product development, and detail level of information; the need to *make it suitable for different target groups* (13|7) including internal and external groups, logistic experts, system and software developer; *easy and suitable for the moment* (10|8) addresses reasons like becoming faster, handling smaller tasks, or fewer involved groups; *different understanding* (10|5) addresses reasons based on ambiguity and assumptions.

4.4 RQ3: What kind of information are covered in ad-hoc requirements?

To identify which kind of information are covered in AhR, we analyzed in two stages the provided requirements artifacts. First focusing on the initial 28 artifacts that included 157 sub-artifacts (C) by inductive coding and later using the full stack of 99 artifacts and their sub-artifacts for a detailed artifact analysis (G). We coded the included information in three categories: *requirements type*, *included sub-artifact*, and information about *multiple projects*. The numbers below indicate code frequency.

As *requirement types* covered in AhR, we identified by multi-coding: software (329), logistic process (125), functional (110), mechatronic (108), quality (52), legal (19), financial (18), strategic (16), change request (13), configuration (7), and others.

We identified a wide range of *included sub-artifacts*: user interface images (40), warehouse and workstation images (32), links refereeing to other sources (23), spreadsheets (22), warehouse process images (17), editable text files (6), PowerPoint presentations (5), PDF files (4), and few unique appearing others.

In all groups, we found that occasionally *multiple projects* are discussed in the same set of AhR, mostly due to the productization of customer requests. We found examples in extensive e-mail asynchronous elicitation and refinement processes, and in meeting notes where requirements from similar projects were discussed and compared (4).

These observations indicate that AhR are used in all levels of the RE process and for all types of requirements, depending on relevance for the process level.

5 Threats to validity

According to Lincoln and Guba, the holy grail of qualitative research, trustworthiness, has four pillars: credibility, transferability, dependability, and confirmability [8]. Below, we discuss the limitations as well as the mitigating strategies we employed.

Credibility concerns whether the collected data accurately represents the studied phenomenon. Our in-depth case study involved extended engagement with the case context and triangulation via a survey (187 respondents that, beside L11, cover all relevant levels of the company RE process in Fig. 2), 22 focus groups with a total of 54 participants, an initial analysis of 28 artifacts provided by 6 employees, and a detailed analysis of 99 artifacts provided by 29 employees that covered all groups L1-L12. To mitigate the subjective interpretation of the survey questions, they were reviewed by all authors and a pilot was conducted with sample employees. The participants could reach out to the first author in case of unclarities; three respondents did so. In the focus groups, time boxing was applied to enable discussing all topics, and the first author acted as a moderator to let everyone speak (mitigating dominance by a single

participant). Finally, we considered not only the frequency of a qualitative code, but also how many data sources confirmed it, and which RE process levels it covers (see Table 1).

Transferability regards the extent to which the findings can be transferred to other situations. We provide thick descriptions of the findings by using multiple data collection methods and by involving a high number of subjects that cover the various levels of the RE process at the company (to boost multivocality). Although our observations seem to indicate that the use of AhR is inherent to large-scale RE processes, this has to be evaluated via follow-up studies.

Dependability concerns how much the study procedures and analysis allow replicability. Within the boundaries of data confidentiality constraints, we do our best to support reliability. We coded data (interviews, survey results, and artifacts) in MAXQDA Analytics Pro 24, offering an audit trail that allows us tracing findings to sources. To support replication in other contexts, we describe the research process and provide an online appendix [18] with survey questions, focus group guideline, and coding scheme.

Confirmability is about ensuring that data and findings are not due to participant or researcher bias. To minimize researcher bias that could occur in social settings, the focus group interviews were recorded, and the first author experienced these data at least three times: during the interview, pre-coding/anonymization, and manual coding. Also, to keep the first author focused, the first three interviews had a separate note-taker. Samples of the coding of artifacts and focus groups were reviewed by the other two authors. Moreover, to confirm the accuracy of the characterization, the research cycle was organized into two main phases: in Fig. 1, steps C&D are explorative, while steps E&F&G are descriptive. This process also helps reducing the bias that could arise by the order in which the data were analyzed. For example, the initial artifact analysis was based 28 artifacts (and 157 sub-artifacts), while the detailed artifact analysis used 99 artifacts. Finally, we conducted member checking of the data (e.g., the artifacts) with their providers, when the data were not fully clear.

6 Related work

We discuss the most relevant literature on various facets of this study: ad-hoc RE processes, informal requirements, and challenges with RE for LASs like those of our case.

Ad-hoc RE processes. The word "ad-hoc" is generally used in RE literature to denote RE processes of limited maturity. As a solution, maturity models were already proposed in the 1990s (e.g., the REAIMS model by Sawyer et al. [14]). Gorschek and Svahnberg [4] provided industry examples of ad-hoc methods for carrying out prioritization and verification. More recently, Todoran et al. [15] revealed that cloud providers elicit consumer requirements in a mainly ad-hoc manner. Klotins and colleagues found that ad-hoc RE processes often correlate with low-maturity companies such as start-ups [7]. While we acknowledge that ad-hoc conducted RE processes may lead to AhR, we focus on a study of the RE artifacts, rather than the RE processes.

Informal requirements. Goguen [3] was one of the first to acknowledge the value of informally represented requirements, stating that vagueness and ambiguity helps in elicitation and discussion, before formalization. These ideas were confirmed by

empirical investigations of industrial practices [9] showing that (i) informal representations of requirements were often used in the early project phases; and (ii) the degree of formality in the derived specifications depends on the type of project, with higher formality in customer-specific projects. Across the decades, informal requirements were often seen as starting point of a formalization process that constitutes one core facet of RE [12]. In the large-scale NaPiRE survey dataset on RE challenges, some observations could be attributed to the fact that informal requirements never get formalized (they remain AhR) and thus cause trouble in later phases. Among the top 5 problems, they list "incomplete or hidden requirements", "reminder for further discussions", and "underspecified requirements that […] allow for various interpretations" [10]. Okpara et al. [11] found that informal, spontaneous *communication* about non-functional requirements to be vital to understanding stakeholder values and needs and for shared understanding. Hussain et al. [5] introduced informal requirements changes (InfRC) that arise when predefined processes are bypassed. They found evidence in a case study company with CMMI-compliant processes. All these studies, which highlight the tension between the costs and benefits of formalizing requirements, motivate our in-depth analysis of the related notion of AhR.

Large-scale RE. RE processes for complex domains and systems (such as LASs) need to scale up not only to more requirements, but also to more and heterogeneous participants that include stakeholders from different disciplines, working for diverse organizational units and globally distributed. In a longitudinal case study concerning scaling up RE processes, Wohlrab et al. [19] found that differences in processes are a common challenge and that the co-existence of multiple processes is likely to lead to misalignments that lead to ad-hoc communicated requirements. Kasuli et al. [6] conducted a study on large-scale RE practices with scaled Agile frameworks. Some of their findings pertain to the context of LAS, such as difficulties in keeping requirements up-to-date, synchronizing system vs. component thinking, managing multiple levels of requirements, and heterogeneous representations. As a mitigation, Wohlrab et al. investigated which artifacts could be considered boundary objects (like architecture descriptions, high-level requirements, and test cases) that support the communication across heterogeneous teams [20]. In this study, large-scale RE is the context and the knowledge delivered by these studies helps us interpret the findings.

7 Conclusion

Problem. In industry, requirements are generally compliant with internal policies and best practices, but they sometimes deviate from academic guidelines. Even though informal or drafted requirements are frequently named in the RE community, and some works reported challenges related to their use [2, 3, 9, 10, 12], there are limited attempts to describe or understand these requirements in detail.

We conducted an in-depth case study at a large-scale global provider of LAS to characterize AhR. Using multi-method research (survey, interviews, and artifacts analysis), we collected evidence of AhR. Our analysis did not focus on quantitative aspects like the proportion of ad-hoc requirements versus guideline-compliant ones. Instead, we qualitatively *dug* into the occurrences of AhR to analyze and characterize them.

Findings. We provided insights into RE practice. Starting from the assumption that the writing style could be a key attribute of an AhR, we built a characterization (RQ1) that includes a quick-and-easy writing style, a pragmatic way of storing them, and written communication in early stages, similar to verbal communication in elicitation.

Practitioners' reported motivations (RQ2) for using AhR include complex documentation needs, time pressure and workload, gaps in the RE tool chain (e.g., missing tools for on-site elicitation in warehouses), and asynchronous written requirement elicitation and refinement. When analyzing which requirement types are covered in AhR (RQ3), we found them to align with the RE process level in which these requirements are used.

Future research. A comprehensive understanding of AhR, the impact of their use, and the potential of optimizing their use is needed. Further research can address the question: What is needed to make AhR good enough for (multi-stage) RE processes? Multiple approaches may be necessary due to the variety of use cases, which include using AhR as interim personal notes; project risk reduction by communicating early requirements for multidisciplinary ideation and refinement; on-site elicitation sessions with limitations due to warehouse and factory work environments. Written asynchronous communication is perhaps the most interesting research area.

We aim to analyze the occurrence of AhR in the evolution of requirements, in order to identify promising use cases. We already considered possibilities such as (1) semi-automatically extracting AhR from sources like OneNote, or E-Mails; (2) transforming AhR by writing or storing them in guideline-conformant ways; (3) including AhR into trace chains of requirements; and (4) semi-automatically identifying changes or conflicts between requirements from different sources including AhR.

Can we apply existing RE approaches to the context of AhR? And can this be semi-automated by encoding expert knowledge into AI-driven tools?

Our observations seem to indicate that AhR can be more likely explained by the use of multi-stage, large-scale RE processes rather than by the specific characteristics of the case company. Future research shall address generalizability.

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