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What Practitioners Really Want: Requirements for Visual Notations in Conceptual Modeling

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Abstract [**Objective:**] This research was aimed at eliciting the requirements of practitioners who use conceptual modeling in their professional work for the visual notations of modeling languages. While the use of conceptual modeling in practice has been addressed, what practitioners in fact require of the visual notation of the modeling languages they use has received little attention. This work was thus motivated by the need to understand to what extent practitioners' requirements are acknowledged and accommodated by visual notation research efforts. [**Method:**] A mixed-method study was conducted, with a survey being offered over the course of several months to LinkedIn professional groups. The requirements included in the survey were based on a leading design theory for visual notations, the Physics of Notations (PoN). After preprocessing, 104 participant responses were analyzed. Data analysis included descriptive coding and qualitative analysis of purposes for modeling and additional requirements beyond the scope of visual design. Statistical and factorial analysis was used to explore potential correlations between the importance of different requirements as perceived by practitioners and the demographic factors (e.g., domain, purpose, topics). [**Results:**] The results indicate several correlations between demographic factors and the perceived importance of visual notation requirements, as well as differences in the perceived relative importance of different requirements for models used to communicate with modeling experts as compared to non-experts. Furthermore, the results show an evolution from trends identified in studies conducted in the previous decade. [**Contribution:**] The identified correlations with practitioners' demographics reveal several research challenges that should be addressed, as well as the potential benefits of more purpose-specific tailoring of visual notation design. Furthermore, the shift in practitioner demographics as compared to those found in earlier work indicates that the research and development of conceptual modeling efforts needs to stay up-to-date with the way practitioners employ conceptual modeling.

Keywords visual notations · requirements · conceptual modeling

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1 Introduction

The first step in making an impact on industry is understanding the requirements of practitioners. Understanding what industry wants has always been of high priority in software engineering (SE) research. The majority of leading SE scientific events include industry tracks, and in 2011 ICSE even held a panel titled "What industry wants from research." In a recent paper [15], Ivanov *et al.* stress that "if the aim of a researcher is to make an impact on industry, understanding what practitioners care about can be a useful guideline to achieve the aim." More importantly, the authors claim that "not only should research results be 'pushed' into the industry, but also it is important to 'pull' the needs of industry."

The phenomenon of "pushing" as opposed to "pulling" has been raising increasing concerns in the requirements engineering (RE) community. Wieringa and Heerkens

[45] claim that most design papers in RE present a solution to a problem, but have neither a validation of this solution nor an investigation of the problems that it can solve. In the context of visual notations, Kaindl et al. [16] propose that for RE to mature, first notational standards should become generally accepted and used, and research should build on what others have done rather than "inventing yet another modelling technique."

Indeed, in the field of conceptual modeling, "pulling" the needs of practitioners, the primary users of modeling languages, is particularly important. Numerous studies have examined *how* modeling languages are used in practice [5,7,27,47]. However, in terms of "pulling" needs from practitioners, an important aspect of conceptual modeling languages has received less attention in research: their interface with the user or their *visual* notation [44].

Visual notations, or the concrete syntax of modeling languages, are the main means by which users interface with conceptual models. The visual design of such models is a key factor in determining their effectiveness in terms of accurately and efficiently conveying the information represented. Approaches have been proposed with guidelines for designing *cognitively effective* visual notations (e.g., [32,13,18]), with the most cited approach in recent years being a theory known as the Physics of Notations (PoN) [32]. Scientific studies applying these principles have mostly "pushed" a variety of new visual notations to the industry [44], whereas "pulling" from industry by actively involving practitioners has typically remained limited in this context [21].

The active involvement of practitioners in designing and evaluating visual notations is of vital importance, as many aspects of cognitively effective visual notation rely on understanding the users and their cognitive make-up [24,46]. For example, while it is well known that accurate interpretation of models can be improved by using rich pictures that suggest their meaning, understanding exactly what a given picture suggests to a group of people requires their active involvement in establishing how exactly they understand such pictures. Failing to achieve such involvement leads to the scenarios that Freudenberg and Sharp describe, in which "software practitioners frequently complain that academic research doesnt meet their requirements or expectations" [10].

This paper focuses on "pulling" from industry in the context of the design of visual notations, exploring *practitioners' requirements of the visual notations they use in industry.* In particular, we focus on three research questions:

RQ1. What requirements do practitioners perceive for the visual notations of the conceptual modeling languages they use?
RQ2. Does the existing theory for visual notation design (in particular, the 'PoN') cover these requirements?
RQ3. Does the existing modeling language landscape cover these requirements?

Naturally, the answers depend on the purpose for which a modeling language is used, as it is widely understood that there has to be a fit between the notation and the mental task to be performed with it [42]. For instance, it is likely that the requirements of a modeling language used among developers or technical experts would differ from those of a language used to communicate with non-technically oriented stakeholders, such as users, business experts, and domain experts.

To address the above question, we conducted an empirical study to elicit detailed requirements from 104 practitioners who employ modeling languages in industry. The rest of this paper is structured as follows. Section 2 discusses related work, while Section 3 details the empirical study we conducted. Practitioner demographics are presented in Section 4 and their requirements for visual notations are given in Section 5. The statistical analysis to assess correlations and the interpretation of the findings are provided in Section 6. Finally, we discuss the implications of these findings for research and development work on visual notation in Section 7.

2 Related Work

2.1 Personal vs. model aspects for notations' understandability

User perceptions of certain design factors have been found to influence the perceived usefulness of visual notations; these perceptions are therefore likely to affect adoption rates of visual notations. [8] Figl and Derntl [8] proposed that taking these findings into account would "enable developers of visual modeling languages to propel the adoption by practitioners by considering the relevant criteria and thus improving the perceived usefulness of a language."

It has been noted that the effect of personal factors on the degree to which models are understood is more important than that of model factors [38]. Thus, the perceived importance of requirements for a model and the visual notation in which it is captured may also differ from person to person. Professional differences between people can give rise to further differentiation. For example, the understandability of a model may be affected by the modeler's original purpose [38]. The way in which models can differ according to the purpose for which they are used has been studied in the context of process modeling [6], but otherwise little empirical work has been accomplished [38]. Similarly, a model's understandability is affected by whether it describes a domain similar to that with which the reader is familiar, which has been studied in, e.g., SE [19].

2.2 Use of conceptual modeling in practice

In two well-known studies, the use of conceptual modeling in practice was investigated [5] [7]. Neither of these studies made specific distinctions between the different aspects of a modeling language, investigating and discussing their comprehensibility overall. Thus, it is difficult to assess what aspects relate more to abstract syntax, concrete syntax, secondary notation, or even pragmatics such as context of use.

In a detailed study on the actual practice of conceptual modeling as an activity, 26 highly experienced professionals were inteviewed. It was noted that, in practice, the purpose that is ascribed to the modeling task strongly affects what is modeled and that considerable variations exist in the value that practitioners ascribe to different modeling activities. [29] Specific tool functionality has been found to positively contribute to the useful of a modeling grammar as perceived by its users. [37]

An empirical study on the needs of industrial users of architecture languages noted that better visualization and usability is the second most lacking feature in architecture (modeling) languages, as well as that modeling support focused on visual modeling and free-hand sketching tools [27] is required. The study consequently concluded that research "should concentrate on supporting these two representation paradigms."

While some of these studies assessed whether professionals deem visual notation important in practice, their exact requirements of visual notation remains understudied. Figl and Derntl's work [8] does address this to a certain degree, but is focused on assessing the perceptions of whether some requirements were satisfied – not on whether they were deemed important by professionals.

2.3 Approaches for the design of visual notations

In addition to research on understanding how professionals do model, there is a multitude of research studies that prescribe how they should model. Several approaches exist, from general ones such as the Guidelines of Modeling [40] and SEQUAL [18], to more specific approaches such as the process-focused 7PMG [28], and to the more strongly visual notation-oriented approaches, such as Cognitive Dimensions [13] for visual programming environments, and the Physics of Notations [32].

The latter has grown to become a widely referenced work on visual notation design. It established a core set of nine principles for cognitively effective notations grounded in theory and empirical evidence from a wide range of fields. An overview of these principles, showing the variety of aspects of visual notations they address, is shown in Table 1.

The challenge in applying this theory (and many other approaches) is that it does not consist solely of requirements that can be straightforwardly operationalized without user involvement [24,22]. Moreover, user involvement is rarely seen in applications [21]. These challenges are further evidenced by the work attempting to formalize or implement the PoN [41,12], which remains limited to those principles that can be "formalized" *a priori*, requiring no empirical knowledge. This strengthens the need to understand practitioners' requirements for visual notations, as understanding what is perceived as most urgent, or prioritized over other aspects, would help researchers effectively apply this theory to suit practical requirements.

The lack of user involvement is not unique to research efforts on visual notation design, as argued in

Table 1 Overview of the PoN's nine principles

Principle	Explanation
Semiotic clarity	There should be a one-to-one correspondence between elements of the language and graphical symbols
Perceptual discriminability	Different symbols should be clearly distinguishable from each other
Semantic transparency	The use of the visual representations the appearances of which suggest their meaning
Complexity management	Notation includes explicit mechanisms for dealing with complexity
Cognitive integration	Notation include explicit mechanisms to support the integration of information from different diagrams
Visual expressiveness	The use of the full range and capacities of visual variables
Dual coding	Use of text to complement graphics
Graphic economy	The number of different graphical symbols should be cognitively manageable
Cognitive fit	Use of different visual dialects for different tasks and audiences

a recent proposal to alleviate such concerns by stimulating active involvement of end-users in the visual notation design [3]. However, this proposal was focused on establishing procedures for actively involving people in the design of visual notations, not on deriving and encoding their requirements for potential later re-use of specific design fragments.

An in-depth case study on selecting the appropriate process modeling notation for an organization [44] shows that requirements elicited from practitioners have a strong similarity to the principles of the PoN theory – giving a first hint that it may potentially be a complete, albeit ambiguous, set of requirements. Similarly, some work exists that addresses the (partial) requirements of practitioners in the context of a specific visual notation being developed (e.g., [14,43]). However, typically no generalization or discussion toward establishing these requirements as re-usable patterns or fragments has been included in such efforts.

3 Research Methods

3.1 Detailed Research Questions

Our general research question is: *What requirements do practitioners perceive for visual notations?* For a satisfactory answer to this question, we need to understand not only what requirements practitioners might find important (and to what extent), but also to what extent research addresses the requirements and whether they are accommodated by the modeling languages used in practice.

RQ1. What requirements do practitioners perceive for visual notations?

To understand what requirements are perceived by practitioners, we investigated:
(a) As requirements for an ideal visual notation, what is the perceived importance of the nine principles of the PoN theory?
(b) What additional requirements, if any, do practitioners perceive that are not addressed by the PoN nine principles?
(c) Which requirements are considered more important than others?
(d) Does the perception of a requirement's importance correlate with any aspect of practitioners' personal or professional demographic?

RQ2. To what extent does existing research address these requirements?

While the first question is focused on eliciting and correlating requirements, we also need to examine the extent to which the current state of the art in visual notation design ''pushes" researchers to design visual notations that address the actual requirements of professionals. To this end, we investigate:
(a) Which requirements elicited in RQ1(b) concern visual notation design, and which concern other aspects, such as secondary notation and tool support?
(b) Do the nine principles of the PoN theory cover all the requirements of practitioners for visual notation design?
(c) Are the remaining requirements, not concerned with visual notation design, addressed by research efforts?

RQ3. To what extent does the existing modeling language landscape satisfy these requirements?

Finally, we address the question of whether, and to what extent, the visual notations used by practitioners satisfy the requirements elicited in RQ1. To that end, we investigated:
(a) Which visual notations are used by practitioners?
(b) To what extent do these visual notations satisfy the requirements considered most important by practitioners, as elicited in RQ1(a)?
(c) To what extent do additional materials (e.g., tools and methods) satisfy the requirements considered most important by practitioners?
(d) If a used visual notation does not adequately satisfy the requirements, is there a salient reason for this?

3.2 Research Protocol

3.2.1 Materials

We distributed a survey using Google Forms. The survey structure, including all the questions as the participants received them, is shown in Appendix A.

To answer the research questions, an approach incorporating both qualitative and quantitative methods was required. To this end, the questions pertaining to the perceived importance of the requirements expressed by the nine PoN principles (survey questions 8–17 and 18–27) were presented as 5-point Likert scale questions, whereas the questions on the detailed additional requirements that practitioners may have were presented as open-ended questions, in order to elicit textual responses to be analyzed via an emergent coding scheme.

The demographic questions were presented as open-ended questions, since we wished to prevent the bias caused by prompting practitioners to respond with a particular view (e.g., the typical purpose for modeling), while other questions were implemented as multiple-select questions with an additional ''other" option (e.g., topics modeled, domains active in).

3.2.2 Pilot

We piloted an initial survey among four professionals with expertise in conceptual modeling techniques. Their feedback was used to verify the estimated time needed to complete the survey and remove any potential misunderstandings in the phrasing. Two participants in the pilot indicated that their answers concerning the importance of each requirement would differ according to whether they were interacting with fellow modeling experts, or other stakeholders without expertise in modeling (e.g., business stakeholders). Accordingly, we divided the survey into two distinct parts, the first focusing on requirements participants held for notations used among fellow modeling experts, and the second to requirements held for notations used among other stakeholders with no modeling expertise. This version was piloted again with the same group, after which no more ambiguities were found.

3.2.3 Participants

We used LinkedIn to approach practitioners who employ conceptual modeling techniques. In particular, we solicited participation in the study via relevant professional groups. We searched first for groups based on keywords such as "conceptual modeling," "requirements," "business analyst," "software architect/engineer," and "enterprise architect/engineer," and then snowballed for more relevant groups by looking through the profiles of members of relevant groups. More detailed demographic data of the participants belonging to the groups that took part in the study are presented in Section 4.

3.2.4 Procedure

We called for participation in 60 LinkedIn Professional Groups likely to be acquainted with conceptual modeling techniques. We posted in several Dutch-language groups, for which the first author translated the message into Dutch. Depending on the group in which we posted, we varied the examples of modeling languages given in order to match those in which members of the group were most likely be interested. For example, in a Dutch-language Enterprise Architecture group we mentioned ArchiMate as one of the example languages.

We invited people to participate in the survey voluntarily, with no incentive given, except stating we would share the results with those interested. The total timespan of the survey was around half a year, with the first posting taking place at the end of October 2016, and the last at the beginning of March 2017. We posted reminders in some of the groups two months after the initial posting to attempt to elicit further responses.

3.3 Data analysis

3.3.1 Pre-processing

In total, we received 108 responses. Before analysis, we pre-processed the data to eliminate any unusable responses. We manually detected suspicious entries, and discarded one response because all the textual answers contained the same repeating nonsensical string and the answer to each Likert scale question was exactly the same.

We excluded participants having experience only in academia. To achieve this, we examined the responses to the domain question, and discarded any participant who listed only academia as the domain. Participants who worked in academia in addition to industry were included. This step led to three additional responses being discarded, ultimately giving us a final set of 104 usable responses.

3.3.2 Descriptive analysis

The personal demographic questions (survey questions 1–3) were collected and tabulated to provide an overview of the relevant findings, as shown in Section 4. We manually processed the country data to ensure no redundancy as a result of remaining synonyms, e.g., "USA," "US," and "United States" being shortened to "USA."

Most of the professional demographic questions (survey questions 4, 6, and 7) were similarly processed. For example, survey question 6 was processed by assessing whether any synonyms existed, that is, whether the same modeling language was referred to by more than one (e.g., misspelled) word. Survey question 5, the typical purpose of modeling, was analyzed qualitatively, as described further in Section 3.3.4.

3.3.3 Quantitative analysis

Through elicitation of quantitative data and further descriptive and statistical analysis, we can answer most of **RQ1**, namely, subquestions **RQ1**(a), (c), and (d). We analyzed Likert scale data strictly considering responses as ordinal data, using the median and the appropriate significance tests. For statistical analysis of the relationship between the Likert scale data and any demographic data, we calculated the Spearman correlation coefficients. Significance was assessed by calculating Fisher's exact test. In addition to the findings discussed in this article, the full output of our statistical analysis can be found in an online appendix.[1]

[1] See www.dirkvanderlinden.eu/data

3.3.4 Qualitative analysis

To answer the remaining questions, we applied a qualitative approach [34] to explore practitioners' perceptions in detail. Data elicited through these questions were first analyzed using exploratory coding [39]. We used a qualitative approach for analyzing the data originating from three questions: survey questions 5 and survey questions 17 and 27, respectively the *typical purpose* of their models and any *additional or missing requirements* practitioners have in addition to the ones presented in the survey.

To code the purpose data, first all three authors independently applied exploratory coding. In a collaborative setting we iterated through the three resulting sets of codes several times, splitting and merging codes determined to be similar. After three iterations of code refinement, we agreed on a coding scheme and applied it to the results of survey question 5. For the data on missing requirements, we separately encoded whether one of the PoN principles addressed the presented requirement and/or whether the requirement was instead related to a different factor, such as tool support or semantic quality instead of the visual notation. We collaboratively merged these coding schemes, resolving any disagreements through discussion.

3.4 Threats to validity

3.4.1 Internal Validity

The primary threats to validity in this study are construct validity (ensuring the survey items mean to the participants what we presume they do [4]), and participant fit (ensuring that the participants are in fact those from whom we wish to gain an understanding of visual notation requirements).

The requirements were presented as the one-sentence summary given by the PoN itself. Given the brevity of their description, it is possible that the participants' interpretation of these requirements were different from that intended; however, given the ambiguous nature of the PoN itself [24], even if given full details of the principles as presented in [32], such differences in interpretation could arise. The high-level descriptions used in our study represent the summarized overall "spirit" of the principles, and are widely used by different applications of the PoN. We therefore worked under the assumption that they serve as an adequate representation of the principles. To further mitigate this threat, we asked participants whether they had any additional requirements that were not included in those presented in the survey. By analyzing the answers to this question and coding them according to whether they were covered by a PoN principle or not, we could ensure that, even if a phrasing was not understood by a participant, any related requirements they may have were elicited through this question.

Participant fit to the study was ensured by limiting the recruitment to relevant LinkedIn groups in order to target only those with experience in conceptual modeling. The profile built by the questions given above further helped to select only those participants with relevant and significant experience. Furthermore, we specifically targeted those with primary industrial experience, and ensured that no participants were included in the datasets whose primary experience was solely of an academic nature.

3.4.2 External Validity

The main threat to external validity is the potential self-selection bias, as we elicited responses only from those practitioners willing to respond. However, in our experience of posting these surveys on LinkedIn, we encountered several groups where one or more participant enthusiastically replied to the survey and encouraged others to join, emphasizing the potential benefit of the insight that the study could also provide to their community. That said, we do not believe that this bias, even if it exists, would have hindered the results; it may have simply helped us to identify more requirements in the case where the participants of the survey were those more aware of the importance of visual notations and their effectiveness.

Other potential threats to external validity may stem from the demographic attributes of the participants. We made every effort to include participants from different geographic regions, cultures, professional domains, and so on. Given the relatively wide spread of the participants in the different demographic attributes, we believe that this risk was well mitigated, for the most part (with the main exception being the typical over-representation of participants from the Western world).

4 Findings: Demographics

4.1 General Demographics

We first established some general demographic data to ensure that the data represent an appropriate sample of participants for deriving requirements held by experienced practitioners. Most of the participants were professionally active in the Western world (European or American countries, representing respectively 33% and 20% of the participants), with a limited number active in the Asia/Pacific (8%), Middle East (5%), and African (2%) regions.

The majority (61%) of participants were experienced practitioners, with more than ten years' professional experience of employing some form of conceptual modeling with visual notations in practice. The remainder of the participants were evenly distributed between having 5 to 10 or less than 5 years of experience (each 19%).

The size of participants' organizations is more evenly distributed, but may not be entirely representative. We learned from participants' feedback that some were employed in major companies, but spent most of their time working as consultants in smaller companies, and others vice versa. Thus, we did not take the size of a participant's organization into account when investigating potential correlations between demographics and perceived requirements.

4.2 Modeling-specific Demographics

This subsection presents modeling-specific demographic data, including the *domains* in which the participants worked, the *topics* they typically modeled, the *modeling languages* they used, and for what *purpose* these modeling efforts were undertaken.

4.2.1 Domains: in what professional context do participants model?

The most commonly occurring working domain in this study was "IT/Software," (48% of participants) with other domains, such as Financial (23%), Services (22%), and Government (19%), following at a distance. Participants were typically active in a single domain (66%). Because most participants were active in a single domain, we could more straightforwardly check for correlations between specific domains and perceived requirements (see Section 6).

4.2.2 Topics: what do participants actually model?

We elicited the topics that participants modeled, allowing multiple answers. In contrast to working in single domains, most participants (87%) worked on multiple topics, with the number of topics ranging from one to five, and the median being three. Interestingly, many participants (70%) modeled processes even if they were not uniquely focused on (business) process modeling, making it one of the most frequently occurring topics. It is likely that this can be explained by the concept of processes being important for the modeling of many things that incorporate them, e.g., enterprise architectures, information flow, flow in software design, and so on.

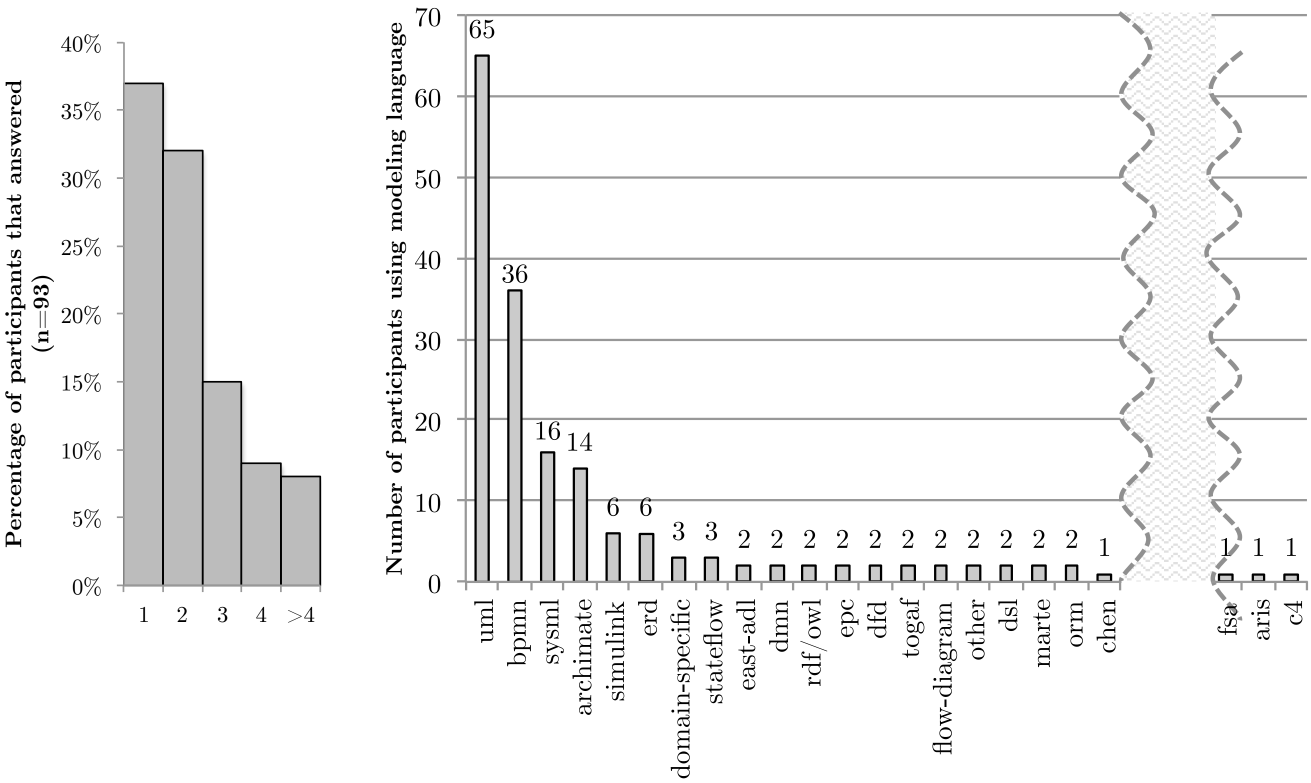
4.2.3 Notation: what visual notation(s) do participants use?

We asked participants in an open question to note the modeling languages they used. Fig. 1 gives an overview of the number of modeling languages used, and which languages in particular were mentioned. The x-axis of Fig. 1(b) is intentionally broken to show the strongly skewed distribution in the relative use of the 58 mentioned modeling languages, most with only a single mention. Shown is UML's relative dominance, followed by BPMN, and to a lesser degree SysML (itself strongly related to UML), and ArchiMate.

Why these notations? The main characteristic shared by UML, BPMN, SysML and ArchiMate is that they are Object Management Group or Open Group standardized notations. This may already indicate a challenge for research on conceptual modeling in that proposed languages and notations may stand little chance of being used in preference to major notations that are regulated by standards committees. Furthermore, the standardization of these languages themselves may hold further challenges for ensuring that they are well designed and cognitively effective, because it is more complicated to make changes to their visual notation than to that of non-standardized languages.

Of further interest is the contrast of these findings to those of earlier work on the use of conceptual modeling in practice. Davies et al. [5] note that the most frequently used notations among their participants (members of the Professional Association for Australia's ICT Sector) were entity relationship (ER) diagrams and data flow diagrams, used respectively by 42% and 34% of their participants. Fettke [7] found that ER diagrams were frequently used by over 50% of his participants (members of the German Computer Society) and data flow diagrams less so, being used by over 20% of his respondents. However, in the study reported here participants mentioned ER diagrams and data flow diagrams only once and four times, respectively. As the earlier work mentioned here targeted IT professionals in general, not those working in a particular application domain, their results should be comparable to ours.

This may indicate changing attitudes in practice toward which notations are used, which carries implications for ensuring that they are well designed. Furthermore, Davies et al. [5] note that, according to their findings, typically younger, less experienced modelers use languages such as UML. Our sample was composed



(a) Number of used modeling languages (b) Used modeling languages (partial representation of 58 total languages)

Fig. 1 Number of modeling languages used by participants, and distribution of the specific languages mentioned.

predominantly of experienced participants, which may further corroborate a shift in attitudes from the previous decade.

Fettke indicated in 2009 [7] that, whereas the use of UML had been rising, that of dataflow diagrams had already declined significantly, but that it remained unclear how rapidly the use of ER diagrams would decline.

Fig. 1 shows that many of the other modeling languages that were mentioned, even those that are far from being a niche language, were used by a single participant. Taken together, these findings indicate a worrying prospect for modeling language and visual notation design, because the adoption of visual notations in practice may be far more difficult than envisioned by some researchers.

As noted in Section 3.4, there are limitations to bear in mind when considering these data, most notably self-reporting bias and selection bias. However, given the wide spread of the targeted LinkedIn groups and the different domains that were reached, in our opinion even in these small-scale results a tendency of practice can be seen among the participants to use general-purpose languages and eschew, from their perspective, more esoteric notations.

4.2.4 Purpose: for what reason do participants model?

We asked participants again in an open question to note for what purpose they typically employed conceptual modeling. Ninety-four non-blank responses were given by participants. Six responses were filtered because they were irrelevant, e.g., where participants noted only terms such as "defence system," "control system," and "UML."

Participants typically modeled for a single purpose. This again made it more straightforward to check for correlations between specific purposes and perceived requirements (see Section 6). Both Davies et al. [5] and Fettke [7] found that database design and management were the most frequently occurring purposes for conceptual modeling. In Table 2, we can see that *design* is indeed still one of the top purposes, although *communication* (frequently concerning the design) is given by most participants as their main purpose. Davies et al. [5] did find that regarding challenges to adoption of conceptual modeling, communication was the primary challenge for continued use of conceptual modeling in organizations.

Table 2 Coded purposes of modeling efforts

Purpose	#	Exemplary quote(s)
Communication	29	"Common point of reference for requirements discussions" "Make the modelled system clear and understandable to various stakeholders" "Bridging communication gaps across diverse groups of stakeholders"
Design	27	"Designing new software." "Systems design."
Understanding	19	"Simplification of complex concepts/solutions" "High level understanding of the system and purpose."
Supporting development	16	"Guide me when actually writing the software" "Supporting decisioning, and instructioning designers"
Representation	15	"Visualisation of architectural metadata" "Visualizing design"
Requirements Engineering	12	"Represent knowledge at different levels of abstraction to look for missing, incorrect, and unnecessary requirements."

5 Findings: Requirements for Visual Notations

5.1 Perceived Importance of Requirements

First, we present the results from the main part of the survey: the Likert scale-based weighting of requirements for visual notations. Fig. 2 shows the distribution of Likert scores for each requirement. Fig. 2(a) shows the distribution when asked about the importance of each requirement while modeling with fellow experts, while Fig. 2(b) shows the importance of each requirement while modeling with non-experts such as business stakeholders or domain experts.

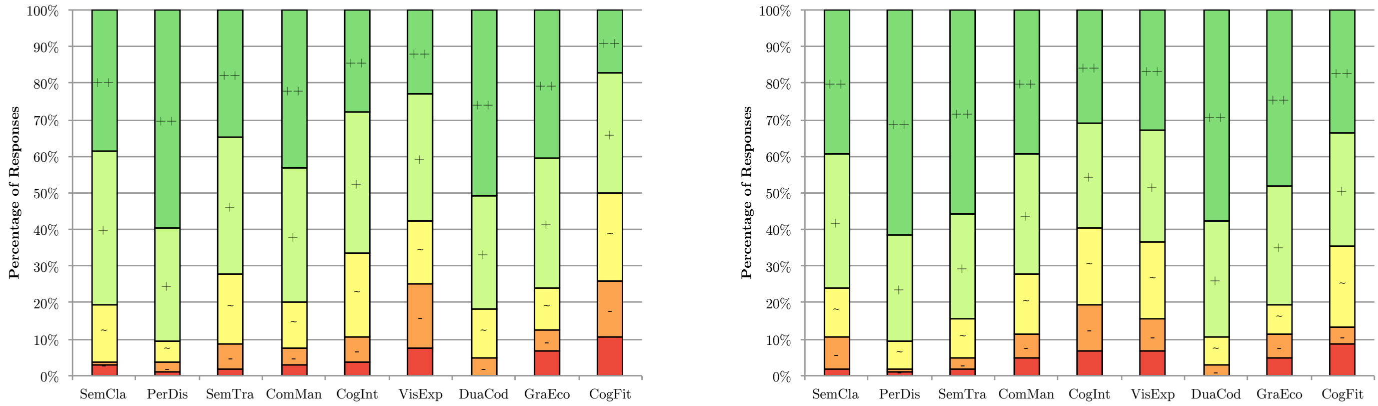
The most important requirement, whether modeling with experts or non-experts, is *perceptual discriminability*: a clear distinction between different symbols. For all other requirements, more differences in the extent of their importance in these two different contexts become apparent. *Dual coding*, for example, is the second most important requirement when modeling with both experts and non-experts. However, here differences become more apparent, as in the case of modeling with non-experts *dual coding*, namely the use of text to complement graphics, there is a 10% increase in the number of participants perceiving it as important. A comparison of the requirements that are deemed important by around 80% or more of the participants in Fig. 2 shows that for modeling with experts *semiotic clarity, perceptual discriminability, complexity management,* and *dual coding* are perceived as most important, while for modeling with non-experts, *perceptual discriminability, semantic transparency, dual coding,* and *graphic economy* are perceived as most important.

Counter-intuitively, the requirement of *cognitive fit*, namely the use different visual dialects for different tasks and audiences, is perceived as important by only 50% and 65% of the participants in the case of modeling with experts and non-experts, respectively. Given the differences between the perceived importance of other requirements, which thus hints at a need for differentiation at least between modeling with experts and non-experts, this may indicate confusion among the participants concerning the exact meaning of this requirement. In this case, the additional requirements elicited and discussed below in Section 5.2 indicate whether such a confusion may have occurred, and whether cognitive fit is indeed less important.

The distributions shown in Fig. 2 seem to hint at some differences between the perceived importance of some requirements depending on whether experts or non-experts in modeling are involved. The median scores for use with experts and non-experts in modeling differ slightly (0.5 to 1) for two principles: (i) semantic transparency, and (ii) cognitive fit. These two requirements are indeed vital to ensure non-experts can better understand a visual notation [32]. These differences are explored in more detail in Section 6. These are explored in more detail in Section 6.

5.2 Categorization of Elicited "Additional" Requirements

After asking participants to rate their perceived importance of each requirement, we asked them whether they had any additional requirements they felt were not addressed. We received 62 responses to this question. We filtered 6 responses as being irrelevant, 5 as being too ambiguous, 17 as addressing requirements only for tool support or model correctness, and 1 as indicating the need for the PoN theory by noting, "The modeling notation should be empirically founded on cognitive theories of visualisation." Two additional responses were filtered out because they addressed requirements for secondary notation (i.e., the arrangement of visual elements atoms, such as their spatial positioning), which is outside the PoN's scope, with one participant noting the need for, e.g., "Visual overlapping of lines, symbols



(a) Distribution of requirements weights (when modeling with experts)

(b) Distribution of requirements weights (when modeling with non-experts)

Fig. 2 Comparison of requirements expressed by participants for visual notations when modeling with, respectively fellow modeling experts, and modeling non-experts.

when for some reason need to cross or be embedded one in another."

Some of the filtered remarks, while discarded for the purpose of this classification, showed that practitioners acknowledge the need for established theory, and perhaps more importantly, examples of good design:

> "How the visual notations are to be used needs to be clearly and well documented, and an expert on their usage needs to offer adequate examples of usage, so you don't end up with what we have now when you google image search for a use case diagram."

From the remaining 31 extracted responses, we retrieved a total of 33 comments to be coded. We coded these data to identify additional or missing requirements, with the three authors independently coding the data. We marked whether, and if so, which PoN principle addressed each proposed requirement. The results are summarized in Table 3.

The results show a link to the aspects in which non-experts were perceived by our participants as more cognitively challenged during model usage, such as the notion of personalizing the notation for different audiences and ensuring that the visual representation used be as simple as possible. In an earlier study on model-aided decision making in Enterprise Architecture [23], we found numerous responses that corroborate this tendency to require simplicity when working with modeling non-experts. For example, one architect noted that PowerPoint, Excel, and Visio were more suitable for non-technical audiences, and another architect noted that in dialogues with management stakeholders they did not use any modeling languages or techniques.

6 Synthesis: Linking Demographics & Requirements

In this section, we explore in more detail the potential correlations between the demographic data we elicited and the perceived importance of each requirement held by each participant.

6.1 Correlations between Requirements

We first investigated the relationship between the perceived importance of the requirements themselves. In the PoN theory, Moody gives a list of trade-offs (see Fig. 3) between different PoN principles. These relationships show that the satisfaction of one such requirement can lead to a positive or negative effect on that of another requirement. For example, satisfying cognitive integration, that is, being able to effectively link different diagrams together, may negatively influence the 1:1 relation between graphical symbols and semantic constructs, as more semantic constructs have to be represented with the same number of graphical constructs. Countering this, by introducing additional graphical constructs, would then negatively influence the graphic economy principle by raising the total number of graphical symbols used in the notation.

We wanted to investigate whether practitioners' perceived importance of the requirements follow these trade-offs, as in some cases they seem rather intuitive. For example, if we were to optimize for graphic economy, that is, the total number of distinct graphical symbols used, we would be forced to reduce the visual expressiveness, as we could not use combinations of visual variables, such as size, color, and texture, to further distinguish

Table 3 Requirements covered by each principle

PoN Principle	#	Exemplary quote(s)
Cognitive fit	14	"I cannot do the formal models without 'artist impressions' or rich pictures tailored to specific stakeholders or stakeholder groups, even fellow modeling insiders/experts." "My responses are coloured by my desire to use these diagrams to collaborate with non - experts, those most familiar with the problem domain" "Highlight how important is to have flexibility to communicate to several audiences perhaps incorporating a more complex visual design. The simplicity of the visual design of UML could be perfect for a software engineer but very cold for a Business User." "Flexibility in presentation."
Complexity management	7	"Visual representation capabilities like zooming in or out" "visual simplication techniques" "Provide different views of complexity level" "use of abstraction (eg a high-level overview)"
Semantic transparency	5	"I think [the] biggest detractor to existing [notations] are that they are conceptually abstract and have steep learning curves."
Semiotic clarity	3	"Precision and unambiguous."
Dual coding	1	"Visual notation needs to have a textual counterpart."
Perceptual discriminability	1	"The size and usability of the symbols"
Cognitive integration	1	"Integration of different domains (business & technology)"'
Visual expressiveness	1	"I just want to point out that personally, I rely heavily on color, being the easiest way to label objects with properties. However, with the number of colorblind people, color alone is insufficient to label anything; it must be used with a different shape, font, size, shading (single or double stripes, stripe direction, etc). That said, it's still important to me to use color along with that other visual cue, because color reminds me of its meaning much faster than trying to figure out the font or shape, etc."

between each symbol, because this would inflate the total distinct graphical symbol count significantly.

We calculated Spearman correlation coefficients for both expert and non-expert matrices, shown in Table 4. Neither matrix contains strong correlations, with only a small number of correlations with an effect size $0.4 \leq |r| < 0.6$, most others being $0.0 \leq |r| < 0.2$. (The highest r is 0.5546 for experts correlating cognitive integration with semantic transparency and 0.40795 for non-experts correlating semiotic clarity with perceptual discriminability a $p < 0.0001$).

This may indicate either that practitioners do not consider the same trade-offs as proposed by Moody, or that, regardless of such trade-offs existing, requirements that may affect each other are still perceived as equally important. Nevertheless, none of the identified correlations *contradict* the trade-offs claimed by Moody.

	Semiotic Clarity	Perceptual Discriminability	Semantic Transparency	Complexity Management	Cognitive Integration	Visual Expressiveness	Dual Coding	Graphic Economy	Cognitive Fit
Semiotic Clarity								±	
Perceptual Discriminability						+			+
Semantic Transparency		+							±
Complexity Management								−	+
Cognitive Integration	−			+				−	
Visual Expressiveness		+						+	±
Dual Coding									+
Graphic Economy		+		+		−			+
Cognitive Fit									

Fig. 3 Trade-offs between the PoN principles, investigated here as requirements, adapted from [32].

6.1.1 Difference between Requirements for Use with Experts and Non-Experts

Following Table 4 and the initial hints of differences established in Fig. 2, we can also compute the delta between the relative importance of the different requirements as perceived by the participants, shown in Table 6. We found that, when comparing the relative importance attributed to different requirements while modeling with fellow modeling experts to that of modeling with non-modeling experts, the correlation between cognitive fit and perceptual discriminability became much less pronounced (a negative change in r of 0.26), while the correlation between cognitive fit and semantic transparency became much more pronounced (a positive change in r of 0.22).

This shows that when models are used to communicate with modeling non-experts, such as business stakeholders, the requirement for ensuring that the symbols used in that particular model suggest their meaning is perceived to be more important than when using the models with modeling experts. This is in line with the need for symbolically and semantically rich graphics, corroborating the findings in Table 3 as to why cognitive fit is considered important after all: because, as a participant put it: "I cannot [create the final] formal

Table 4 Principle-principle correlations. Given in the table is the r for each principle-principle combination according to Spearman Correlation Coefficient. Values in *emphases* have an $r \geq 0.2$ and are statistically significant with a $p < 0.05$.

Modeling with fellow modeling experts									
	SemCla	PerDis	SemTra	ComMan	CogInt	VisExp	DuaCod	GraEco	CogFit
SemCla	1	–	–	–	–	–	–	–	–
PerDis	*0.34184*	1	–	–	–	–	–	–	–
SemTra	0.01461	0.1148	1	–	–	–	–	–	–
ComMan	*0.2106*	*0.23088*	0.14692	1	–	–	–	–	–
CogInt	0.17692	0.12643	0.05546	*0.30433*	1	–	–	–	–
VisExp	-0.014	0.09154	*0.25582*	0.07488	0.15495	1	–	–	–
DuaCod	0.09811	0.00435	-0.0726	-0.01581	0.09404	0.16225	1	–	–
GraEco	-0.03626	*0.22694*	0.08237	0.12164	0.04298	-0.02485	-0.02643	1	–
CogFit	0.12621	*0.24773*	-0.00546	0.1356	0.08747	0.31836	0.00778	0.08341	1
Modeling with stakeholders without expertise in modeling									
Effect	SemCla	PerDis	SemTra	ComMan	CogInt	VisExp	DuaCod	GraEco	CogFit
SemCla	1	–	–	–	–	–	–	–	–
PerDis	*0.40795*	1	–	–	–	–	–	–	–
SemTra	0.13347	0.03844	1	–	–	–	–	–	–
ComMan	*0.29797*	*0.23789*	0.15429	1	–	–	–	–	–
CogInt	*0.24573*	*0.30656*	-0.01576	*0.38724*	1	–	–	–	–
VisExp	-0.04654	0.01555	*0.32432*	0.01123	0.12045	1	–	–	–
DuaCod	-0.06808	0.03038	0.01749	-0.00424	0.11142	*0.34969*	1	–	–
GraEco	0.0908	*0.29084*	*0.26799*	0.04191	-0.02456	0.16612	0.08581	1	–
CogFit	0.04852	-0.01137	*0.21145*	0.0025	0.14162	0.26788	0.11944	0.07557	1

models without 'artist impressions' or rich pictures tailored to specific stakeholders or stakeholder groups."

6.2 Clusters of Requirements

We attempted to find clusters in the perceived importance of requirements (e.g., to find that the perceived importance of semantic transparency and of graphic economy is related) by performing a factor analysis. The factor analysis identified three factors in the scores for use of models with fellow experts and four factors in the scores for use of models with non-modeling experts.

These factors mean that there is a statistical correlation between the scores for, e.g., Visual Expressiveness, Dual Coding, and Cognitive Fit (the second factor found for requirements when modeling with experts). To verify whether this factor is meaningful, we needed to link it to an explanation grouping these requirements together. For example, in earlier work [24], the PoN principles were grouped on the basis of the challenge required for their implementation, and in a recently proposed framework for applying the PoN [22], the PoN principles were grouped on the basis of the information that is required to verify each principle.

However, a comparison of the factors showed that no matching sets of factors became clear. Perhaps this lack of matching between factors shows that the practitioners' perception of these requirements cannot be predicted on the basis of what we know about the principles in general. Instead, their perceptions must be understood in terms of the practical context; that is, how the things on which practitioners work and how they work on them influence their perceptions of these requirements. Thus, with no clear empirical grounding for what ordering or real-world variables explain the statistically identified factors, we do not treat them as meaningful clusters, proceeding instead to address each principle individually.

6.3 Correlations between Requirements and Demographic Factors

We performed a further correlation analysis between each of the requirements (nine principles for use with experts, nine principles for use with non-experts) and all demographic data (topics, domains, etc.)[2]. Table 5 summarizes the identified (borderline) significant correlations according to Fisher's exact test. We identified correlations between a number of *domains* and requirement importance, the exclusive use of UML and requirement importance, the use of an exclusive specific purpose and requirement importance, and the number of purposes and requirement importance.

These correlations show, in particular for the domains of Government and IT/Software, that there are a number of preconceptions concerning which aspects of visual notation design are deemed most important. Taken together, these correlations may lead to a more tailored approach of the PoN for visual notation design. This is discussed in more detail in Section 7.

[2] See the full output of the statistical analysis at `www.dirkvanderlinden.eu/data`.

While we initially wished to assess correlations between topics and the perceived importance of specific requirements, the nature of the elicited data made this infeasible. Most practitioners work on multiple topics (the median being three), whether concurrently or alternatingly. However, from a cognitive point of view, the *number* of topics on which one works could be expected to affect the perception of certain requirements, as switching between diagrams for different topics might similarly imply differing requirements. We used a Spearman correlation coefficient here also to assess the correlation between the number of topics and each requirement's perceived importance. Surprisingly, no statistically significant correlations were found. Two borderline significant correlations were found, albeit with small effect sizes. These are the perceived importance of visual expressiveness for use with experts ($p = 0.0562$) and the perceived importance of cognitive integration for use with non-experts ($p = 0.0709$).

7 Discussion

In the following, we discuss some further insights arising from our analysis, and summarize the answer to each of the research questions.

7.1 Completeness of PoN Principles

One of the most interesting findings was that the requirements for visual notations elicited from our participants are *all* covered by the PoN principles – at least in theory. Moreover, no requirements related to the design of notations that did not map to some PoN principle were mentioned. This essentially reinforces the PoN as a potentially leading approach for the design of visual notations, which is *complete* in the sense that it covers all the important requirements practitioners may have. This, of course, does not imply that the PoN principles can be easily operationalized in a visual notation, as discussed in [24, 26]. Moreover, it is likely that they cannot be fully satisfied, as the PoN principles are not independent, and that one principle is satisfied may imply that it impossible to satisfy another. For example, improving the notation's intuitive understandability by employing rich pictographs affects the complexity of drawing by hand, as well as the ease of distinguishing between different pictographs, depending on their design. In isolation, both requirements are very important for most practitioners, but design choices made when implementing a concrete visual notation require the active involvement of its intended users [21].

Summarized answer to **RQ1**, *What requirements do practitioners perceive for visual notations:* All the nine principles of the PoN theory are considered important by practitioners (**RQ1a**) and represent a complete coverage of requirements for primary visual notation (**RQ1b**). Some requirements are considered more important than others, showing a differentiation in the perceived importance of requirements when using models with modeling experts or non-experts. (**RQ1c**). The analysis in Section 6.3 shows that there are correlations between certain aspects of a practitioner's demographic data and the amount of importance they attach to certain requirements (**RQ1d**).

7.2 Outside the scope of PoN principles

As reported, the requirements that fall outside the scope of the PoN principles typically do not refer directly to the visual notation itself, but to the way it is actually used. A repeated requirement expressed by participants is that they would like to be able to draw diagrams by hand, and then be supported in converting them to digital models.

Others re-iterated that it is important for a visual notation to be easy to draw by hand, going so far as to note free-form utilization of the notation is the most important criterion for adaption, and they would not be able to produce formal models without first producing less constrained freehand sketches. This further demonstrates a gap between how the visual notations are expected to be used and the way they are actually used in practice.

Another, complementary issue mentioned by participants is the possibility of modeling with the support of computer-based tools. In fact, when it is necessary to encode models using more formal means, it becomes vital that a visual notation has tool-support, including support for zooming in or out, animation, dynamic filters, and so on, are all aspects desired by practitioners – for which there needs to be adequate tool support for the visual notation.

7.3 Should we stop "pushing" modeling notations?

The very small number of visual notations used by significant numbers of people in practice is also a noteworthy finding. The main notations used by practitioners (UML, BPMN, SysML, ArchiMate) are regulated by standardization bodies. Perhaps this should be taken as a message to academia to stop '"pushing" new visual notations to the industry and attempt instead to "pull" the changes that practitioners want in the already existing notations they in fact use. An important point in this context is the expressed need for more visual variability in the context of using such standardized notations, as one participant stressed: "[it is important that] standardized visual notation used by everyone; different views generated depending on people's role but keeping the same notation."

Ensuring that the notations actually used in practice are as cognitively effective as they can be should thus be an important research direction. All four of these languages have been analyzed to some extent using the PoN, although the completeness and thoroughness of those applications differs [20]. Findings of such work, and their implications for the language's visual design should not remain solely in the context of academic articles, but be directed towards the actual standards.

Summarized answer to **RQ2**, *To what extent does existing research address these requirements:* The requirements elicited did not concern only visual notation design, as they included requirements for correctness and support (17 requirements) and secondary notation (2 requirements). (**RQ2a**). Nonetheless, as noted previously, for those requirements concerning primary visual notation, the PoN principles as used in the questionnaire seem to cover all the requirements practitioners attach to primary visual notation design (**RQ2b**). However, to ensure that the application of the PoN to a visual notation covers all these requirements, involving them in the operationalization of each principle is vital.

7.4 Meaningful (visual) variability

From the practitioners' responses it becomes apparent that there is a need for visual dialects *within* the languages they use, which should be tailored to modeling experts and non-experts. As noted by one participant, flexibility is needed to communicate to several audiences, because what works for a software engineer will not necessarily work for a business user.

Variability in the context of modeling languages has received attention in the literature, such as the need for systematic ways to create dialects of enterprise modeling languages [2]. However, such work remains primarily on the level of meta-models describing which entities exist, namely, the abstract syntax. To define or describe a modeling language fully this is not sufficient, as both semantics (what things mean) and the concrete syntax, or visual notation (how things look), are important [17]. Meta-modeling approaches grounded in the OMG Meta-Object-Facility (MOF) [36] have been proposed for extending the degree to which visual notations are systematically captured and linked to their meta-models [9,33]. Related approaches for detecting inconsistencies between such definitions of visual notations and meta-models have also been proposed [1]. In some of this work, the option of multiple visual notations for a single meta-model [17] is explicitly noted. The conclusion is reached that multiple visual notations can be used provided that the underlying meta-model is well defined and serves as a common (abstract) representation of the actual information represented in the model. However, these studies predate insights provided by the PoN theory, which show diagram-level aspects of design known to be important for ensuring that non-experts can parse models effectively. In particular, it is now understood that *meaningful* variations in concrete syntax to bridge the expert–non-expert gap amount to more than mere differences in the symbols or color schemes used. Some examples of such variation are [32]:

- Targeted iconographic design to suggest meaning: non-experts are aided by the use of rich pictures that suggest their meaning clearly.
- Use of visual complexity management mechanisms: non-experts may find it difficult to parse models that do not incorporate any mechanisms to abstract and hide information, and have to mentally "chunk" elements into sub-diagrams.
- Variation in the number of visual variables used to discriminate between visual elements: non-experts may benefit from graphical symbols being distinguished by more than just shape or color.
- Variation in the size of the visual vocabulary: non-experts are challenged by notations with a high number of distinct graphical symbols.

However, can we practically support such variation in the realistic context of the standardized modeling languages that practitioners use? A look at the two largest languages in terms of users, UML and BPMN, shows there is significant tension between respecting the use of standardized languages and implementing the visual dialects practitioners want.

UML allows a designer to adapt the notation to a specific context by using stereotyping, which allows the use of both *specific terminology* and *[visual] notation* [35, sec. 12.3.3.4]. The extent to which a new notation can be introduced is limited, however, to primarily new symbols and coloring. It is possible to append a symbol to stereotyped entities as a marker or to display them as that symbol entirely.

This allows at least for the use of rich pictures: the use of detailed iconographic representation for domain concepts. However, there is a significant limitation in that these visual modifications seem to be allowed only for stereotyped elements. This means that new elements in the abstract syntax have to be created and the semantics defined, instead of allowing simple visual variability in the representation. The existence of numerous tool-specific extensions to allow for modification and coloring of core elements (e.g., in Visual Studio) seems to be a clear hint at people implementing this need themselves. Similar to UML, BPMN extensions, the primary means of visual modification in practice seems to be coloring and the addition of markers to existing graphical elements [25]. There are concrete instructions in the standard for BPMN [36] for extending its notation. Particularly salient are:

– "A new shape representing a kind of Artifact MAY be added to a Diagram, but the new Artifact shape SHALL NOT conflict with the shape specified for any other BPMN element or marker."
– "An extension SHALL NOT change the specified shape of a defined graphical element or marker (e.g., changing a square into a triangle, or changing rounded corners into squared corners, etc.)."

The same restriction as in the UML standard is found again: that existing elements may not be meaningfully changed. Shape, color, and line style of existing core constructs are all protected. This impacts the practitioner's ability to create a meaningful variability in the visual notation, as properties of the core constructs would be modified to deal with practitioners' needs. It could be argued that allowing changes to the core constructs' representation would impact the *mutual intelligibility* of the models created. However, as practitioners clearly indicate such variability would be used to communicate between an expert audience (e.g., developer, technical analysts) and a non-expert audience (e.g., business stakeholders, management, end-users), there is no need for each group to read the same underlying model as that in the visual representation optimal for the other group. Therefore, the challenge of mutual intelligibility does not come into play. The ability to support practitioners with the meaningful visual dialects they require in standardized language such as UML and BPMN – especially when these require non-trivial changes such altering visual variables, visual vocabulary size, or complexity mechanisms – thus seems to be an inherent contradiction.

Summarized answer to **RQ3,** *To what extent does the existing modeling language landscape satisfy these requirements:* The predominant visual notations used by practitioners (**RQ3a**) are UML, BPMN, SysML, and ArchiMate. The literature reports on applications of the PoN theory to most of these notations, showing that they tend to be lacking in terms of several PoN principles (cf. UML/SysML [31], BPMN [11], ArchiMate [30]), and we can therefore deduce that they do not satisfy the requirements considered important by practitioners (**RQ3b**). While there are some additional, non-standard tools that are used by some in practice to alleviate such issues (e.g., color-coding plugins for Visual Studio) (**RQ3c**), it is likely that the most salient reason for these visual notations not adequately satisfying the requirements is related to their nature as standardized languages and as such resistant to change (**RQ3d**).

8 Summary and Concluding Outlook

This article presented a study on the requirements held by practitioners for visual notations of conceptual modeling languages. One important conclusion is that the empirical evidence presented in this paper supports the view of the PoN as a guiding theory for the design of visual notations that is well aligned with practitioners' requirements. It should be noted that to actually meet those requirements, the PoN has to be applied carefully and taking into account the intended users of the visual notation, which is a non-trivial task. Moreover, we should go beyond the visual design of notations and explore the question of *how* the models will be used: the ability to draw models by hand and the availability of sophisticated tool support are both concerns raised by practitioners that should be taken into account.

Another insight from our study is that the primary visual notations used in practice are those regulated by standardization bodies. Practitioners would like visual variability to be introduced and the ability to define different visual dialects, features that go beyond what is currently allowed by these standards. This is a point that requires further collaboration between the research community and the industrial parties to ensure that the languages used in practice can satisfy their users' requirements. Perhaps the most important take-away message from this study is that academic research should stop "pushing" new notations to industry. Instead, we should explore the problems related to the existing widely used notations and attempt to improve them according to the needs of industry.

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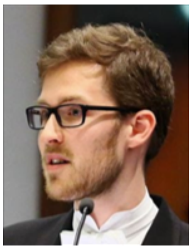

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Appendices

A Survey structure

Personal demographics:

1. What country do you work in?
   [ ]
2. How many people are employed in your organization?
   ○ Less than 100
   ○ Less than 1000
   ○ Less than 10.000
   ○ More than 10.000
3. How many years have you used modeling languages in a professional setting?
   ○ Less than 5 years
   ○ 5 to 10 years
   ○ More than 10 years

Professional demographics:

4. What do you mostly model?
   ☐ Processes
   ☐ Goals/Motivations
   ☐ Information/Data
   ☐ Requirements
   ☐ Architecture (Software)
   ☐ Architecture (Enterprise)
   ☐ Other: ...
5. What is the typical purpose of your models?
   [ ]
6. What modeling language(s) do you have significant experience with?
   [ ]
7. What domain do you currently work in?
   ☐ Services
   ☐ Manufacturing
   ☐ Telecom
   ☐ Financial
   ☐ Health
   ☐ Government
   ☐ Academic
   ☐ IT/Software
   ☐ Other: [ ]

Visual notation requirements
Part I – Among fellow modeling experts
Suppose that for your modeling efforts you would be able to have an ideal visual notation, suited especially to your purposes. You would be using this notation only among fellow modeling experts. On a scale of 1 to 5, how important would the following requirements be for this notation? It should ...

8. ... have a 1:1 correspondence between semantic constructs and graphical symbols
   not important at all ○ ○ ○ ○ ○ very important
9. ... clearly distinguish between different symbols
   not important at all ○ ○ ○ ○ ○ very important

10. . . . use visual representations whose appearance suggests their meaning
not important at all ○ ○ ○ ○ ○ very important

11. . . . have explicit mechanisms for dealing with complexity
not important at all ○ ○ ○ ○ ○ very important

12. . . . have explicit mechanisms to support integration of information from different diagrams
not important at all ○ ○ ○ ○ ○ very important

13. . . . use the full range and capacity of visual variables such as shape, color, size, etc.
not important at all ○ ○ ○ ○ ○ very important

14. . . . use text to complement graphics
not important at all ○ ○ ○ ○ ○ very important

15. . . . have no more than a cognitively manageable number of different graphical symbols
not important at all ○ ○ ○ ○ ○ very important

16. . . . use different visual dialects for different tasks and audiences
not important at all ○ ○ ○ ○ ○ very important

17. Are there any requirements you feel are not covered by the ones you just saw, specific to the use of a visual notation among fellow modeling experts?

Part II – Among other kind of stakeholders
Suppose again that for your modeling efforts you would be able to have an ideal visual notation, suited especially to your purposes. You would be using this notation also with other stakeholders that have no expertise in modeling, such as business experts or end-users. On a scale of 1 to 5, how important would the following requirements be for this notation? It should. . . . . .

18. . . . have a 1:1 correspondence between semantic constructs and graphical symbols
not important at all ○ ○ ○ ○ ○ very important

19. . . . clearly distinguish between different symbols
not important at all ○ ○ ○ ○ ○ very important

20. . . . use visual representations whose appearance suggests their meaning
not important at all ○ ○ ○ ○ ○ very important

21. . . . have explicit mechanisms for dealing with complexity
not important at all ○ ○ ○ ○ ○ very important

22. . . . have explicit mechanisms to support integration of information from different diagrams
not important at all ○ ○ ○ ○ ○ very important

23. . . . use the full range and capacity of visual variables such as shape, color, size, etc.
not important at all ○ ○ ○ ○ ○ very important

24. . . . use text to complement graphics
not important at all ○ ○ ○ ○ ○ very important

25. . . . have no more than a cognitively manageable number of different graphical symbols
not important at all ○ ○ ○ ○ ○ very important

26. . . . use different visual dialects for different tasks and audiences
not important at all ○ ○ ○ ○ ○ very important

27. Are there any requirements you feel are not covered by the ones you just saw, specific to the use of a visual notation among fellow modeling experts?

B Correlations between requirements and demographics

Table 5 Correlations between requirements and demographics. Correlations with borderline and significant p-values are shown. Significant correlations with $p < 0.05$ are highlighted in **bold**.

Aspect	**Relationship**	**Requirement**	**Context**	p
		Domain correlations		
Financial	places high importance on	Semiotic Clarity	Expert	0.0842
Government	places less importance on	Semiotic Clarity	Expert	**0.039**
Government	places high importance on	Semantic Transparency	Expert	0.0859
Government	places high importance on	Complexity Management	Expert	0.064
Government	places less importance on	Dual Coding	Expert	0.0782
Government	places much less importance on	Cognitive Fit	Expert	0.0693
Government	places less importance on	Semiotic Clarity	Non-expert	0.0541
IT / Software	places less importance on	Complexity Management	Expert	0.058
IT / Software	is fully polarized	Cognitive Fit	Non-expert	0.0535
		Modeling language correlations		
users of *exclusively* UML	place high importance on	Visual Expressiveness	Expert	**0.003**
users of *exclusively* UML	place high importance on	Visual Expressiveness	Non-expert	**0.0201**
		Modeling purpose correlations		
Design	is more centralized	Cognitive Integration	Non-expert	0.0618
Design	places less importance on	Graphic Economy	Expert	0.0688
Development support	places less importance on	Cognitive Fit	Non-expert	**0.003**
Requirements Engineering	places much less importance on	Visual Expressiveness	Expert	**0.0383**
Requirements Engineering	places less importance on	Semantic Transparency	Non-expert	**0.0133**
Understanding	places less importance on	Visual Expressiveness	Expert	**0.0328**
Understanding	places less importance on	Complexity Management	Non-expert	0.0537
		Number of modeling purpose correlations		
One purpose	places more importance on	Cognitive Integration	Expert	**0.0157**
One purpose	places more importance on	Semantic Transparency	Expert	**0.0493**

C Delta between requirements towards modeling expert and non-expert use

Table 6 Delta between perceived importance of requirements when modeing with experts and with non-experts. Differences ≥ 0.15 are shown in **bold**.

	SemCla	PerDis	SemTra	ComMan	CogInt	VisExp	DuaCod	GraEco	CogFit
SemCla	0	–	–	–	–	–	–	–	–
PerDis	0.06611	0	–	–	–	–	–	–	–
SemTra	0.11886	-0.07636	0	–	–	–	–	–	–
ComMan	0.08737	0.00701	0.00737	0	–	–	–	–	–
CogInt	0.06881	0.18013	-0.07122	0.08291	0	–	–	–	–
VisExp	-0.03254	-0.07599	0.0685	-0.06365	-0.0345	0	–	–	–
DuaCod	-0.16619	0.02603	0.09009	0.01157	0.01738	0.18744	0	–	–
GraEco	0.12706	0.0639	0.18562	-0.07973	-0.06754	0.19097	0.11224	0	–
CogFit	-0.07769	**-0.2591**	**0.21691**	-0.1331	0.05415	-0.05048	0.11166	-0.00784	0