A Sustainability Requirements Catalog for the Social and Technical Dimensions

Diogo Albuquerque[1], Ana Moreira[1[0000−0003−2046−2766]] ✉, João Araujo[1[0000−0001−5914−1631]], Catarina Gralha[1[0000−0002−3622−7851]], Miguel Goulão[1[0000−0002−5356−5203]], and Isabel Sofia Brito[2[0000−0002−7556−4367]]

[1] NOVA LINCS, School of Science and Technology, NOVA University of Lisboa, 2829-516 Caparica, Portugal
dh.albuquerque@campus.fct.unl.pt, {amm, joao.araujo, catarina.gralha, mgoul}@fct.unl.pt

[2] UNINOVA-CTS, 2829-516 Caparica, Polytechnic Institute of Beja, 7800-295 Beja, Portugal
isabel.sofia@ipbeja.pt

Abstract. Sustainability poses key challenges in software development for its complexity. Our goal is to contribute with a reusable sustainability software requirements catalog. We started by performing a systematic mapping to elicit and extract sustainability-related properties, and synthesized the results in feature models. Next we used iStar to model a more expressive configurable catalog with the collected data, and implemented a tool with several operations on the sustainability catalog. The sustainability catalog was qualitatively evaluated regarding its readability, interest, utility, and usefulness by 50 participants from the domain. The results were encouraging, showing that, on average, 79% of the respondents found the catalog "Good" or "Very Good" in endorsing the quality criteria evaluated. This paper discusses the social and technical dimensions of the sustainability catalog.

Keywords: sustainability requirements modeling · non-functional requirements · sustainability requirements catalog · goal modeling

1 Introduction

Sustainability implies *development that meets the needs of the present without compromising the ability of future generations to meet their own needs* [6]. This challenge calls for the integration of social equity, economic growth, and environmental preservation, considering also their effects on each other. These three dimensions have been integrated in a multidimensional line of thought that also encompasses an individual and a technical dimension [24]. Each dimension addresses different needs (e.g., improve employment indicators, reduce costs, reduce CO2 emissions, promote high agency, and easy system evolution) and impacts on the others and respective stakeholders. Therefore, sustainability-aware systems differ from other types of systems in that their functionality must explicitly balance the trade-offs between these dimensions.

Despite lacking a common definition in Software Engineering, existing works in software development handle sustainability as a non-functional requirement (e.g., [27]). We follow the view that sustainability is "an emergent property of a software system" [30]. As an emergent property, sustainability cannot be added to a specific part of the software system during later activities of software development nor should it be looked into in isolation. In this work, we look at sustainability as a complex composite quality attribute, formed of five complex aggregates of quality attributes, one for each dimension, which, in turn, is composed of the quality attributes relevant for that dimension. Given the complexity of sustainability and the lack of approaches to help with the identification and analysis of sustainability requirements and their integration with other system's requirements, reusable artifacts can contribute to alleviate this complexity.

Our goal is to develop a reusable sustainability catalog that can be configured for different contexts and purposes. Our stating point was a systematic mapping study to gather from the existing body of knowledge the fundamental sustainability properties. The extracted concepts of each sustainability dimension were synthesized using feature models [15], to represent common and variable features (or concepts). Given that feature models lack the means to represent certain types of concepts and relationships needed for sustainability, we mapped their features and relationships to iStar 2.0 [11], a goal-based requirements description language, and specified the missing information. The iStar framework provides means to support (i) a clear separation between elements such as goals, qualities, tasks and resources and (ii) different types of relationships, such as contributions. Finally, we implemented an extension to the piStar tool [26], offering configuration operations (e.g., add, select, project/filter, export) to extract subsets of the catalog according to the problem domain needs and stakeholders' preferences.

We qualitatively evaluated the sustainability catalog and its guide regarding their readability, interest, utility and usefulness. We sent a questionnaire to 89 participants, including the authors of the selected primary studies from our mapping study. 16 out of 50 respondents are among those authors. 79% of the respondents "Agree" or "Strongly agree" that the catalog fulfills the quality criteria. This paper focuses on the social and technical sustainability dimensions.

This paper is structured as follows. Section 2 summarizes the results of a mapping study aiming at collecting sustainability concepts and relationships and synthesizes the results in feature models. Section 3 refines the various concepts and models them using an iStar goal model. Section 4 discusses the implementation of the tool support, and Section 5 discusses the results of the qualitative evaluation performed. Finally, Section 7 presents related work and Section 8 draws the conclusions and offers ideas for future work.

2 Sustainability concepts and relationships

This section summarizes the results of a systematic mapping study and finishes with a feature model synthesizing the information found. A mapping study process consists of planning, conducting, and reporting [25]. The planning phase defines the research questions, the search and study selection strategy, and the data extraction form. The conduction phase shows the execution of the search while presenting the results for each research query. The reporting phase analyzes and presents the results given in the previous phase.

2.1 Eliciting concepts: planning and conduction

We started by formulating the research questions and respective search string to run in the DBLP digital library, as it compiles a large amount of publications from different sources (e.g., IEEEXplore, ACM, Science Direct, SpringerLink). The general research question *What are the requirements that contribute or relate to sustainability?* was derived after a PICOC analysis. With variants of the keywords in the research question, we built the search string *(method OR process OR technique OR model OR tool OR approach OR framework OR catalog OR catalogue) AND (sustain* OR green) AND (requirement OR attribute)*. The inclusion and exclusion criteria (typical ones) were defined to help selecting the relevant studies for analysis and data extraction. The search was performed automatically, and then manually, via forward and backward snowballing.

We run the search string on DBLP which indexes the relevant fora in computer science, retrieving 169 candidates. First, papers were select based on title and abstract reading and then the selected studies were fully read for data extraction, resulting in 7 papers [12, 7, 3, 8, 2, 28, 10]. After snowballing, 5 more articles [19, 20, 22, 27, 24] more studies were added to the final list of papers.

2.2 Discussion and synthesis of results

Primary studies discussing software sustainability and its importance ([12], [7], [3], [8], [2]), models and frameworks ([28], [19], [24]), requirements and sustainability relationships [10] were essential for this part of our work. Sustainability has often been equated with environmental issues, but it is clear that it requires simultaneous considerations of social and individual well-being, economic prosperity and the long-term viability of technical infrastructure [2, 24]. Thus, a sustainable product should balance the goals of these dimensions. This is hard due to intra- and inter-dimension relationships among properties within one dimension and across different dimensions. The set of selected papers provided valuable information about relationships (some also available in [9, 17, 4]).

The synthesis of the results are expressed in a feature model [15], representing sustainability properties as features and relationships as constraints between features. Each model offers a view of each dimension and captures information about common and variable features at different levels of abstraction. Even though our study is broader and includes the environmental and economic dimensions, we chose to discuss in this paper, the social and technical dimensions.

Social dimension The social dimension relates to societal communities and the factors that erode trust in society [3]. It can also be seen as the well-being of humans living in such society [20]. This dimension is related to notions such as, honesty, transparency, communication, security and safety [3]. This dimension is divided into *satisfaction* (of the stakeholder), *security* (of the system) and (social) *safety*. Satisfaction can be linked with *usefulness* (the achievement of pragmatic goals), *trust* (confidence in the company), and *fairness* (regarding equality and honesty) [10, 13]. Security is an important requirements of the social dimension [10], as systems' data and information cannot be compromised, hence divided into *confidentiality*, *authenticity*, *integrity*, and *accountability* [14]. Safety is divided into *freedom from risk* (i.e., mitigation of the potential risk to people [13]) [10] and *legislation* [22] (compliance with the laws and legislation). A few relationships were also elicited. In particular, security increases trust of stakeholder (represented by a *requires* relationship), since a secure system is one that inspires trust to the user [13]. A system's authenticity requires both its integrity and its accountability [14]. However confidentiality may be prejudicial for accountability [14], since it could be harder to trace the origin of the data, due to possible anonymity. The feature model in Figure 1 expresses the decomposition of the dimension and the various relationships among features, where optional operators were used to allow flexibility to the decision maker.

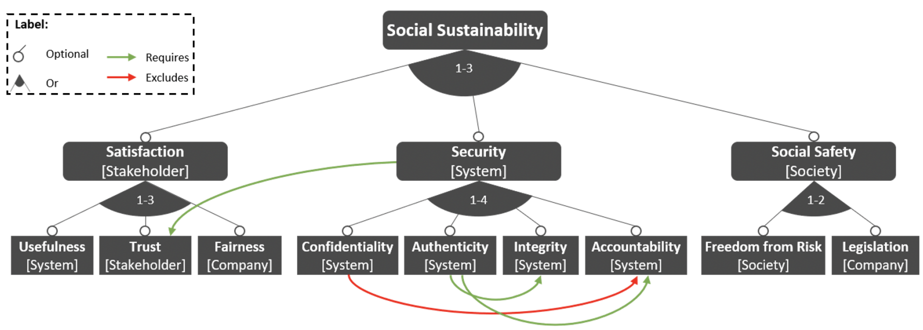

Fig. 1. Feature model for the **social** dimension.

Technical dimension This dimension has the central objective of long-time usage of systems and their adequate evolution with changing surrounding conditions and respective requirements. It refers to maintenance and evolution, resilience, and the ease of system transitions [3], and is divided into *functionality*, *maintainability*, *compatibility* and *reliability* of the system. Functionality is linked with *functional appropriateness* (everything works as intended) and *functional correctness* (lower possibility of occurring internal errors and/or failures) [10]. Maintainability is important to guarantee how well a system is maintained, and it is divided into *testability* (effectiveness and efficiency with which test criteria can be established [14]), *modularity* (components may be separated and recombined, often with the benefit of flexibility and variety in use, with minimal impact on other components [14, 16]), and *modifiability* (changes to a software system can be developed and deployed efficiently and cost effectively [14]). Compatibility is divided into *adaptability* (ability to adapt to constant changes) and *interoperability* (ability to couple of facilitate interface with other systems). Finally, reliability [3] is divided into *availability* (the system is able to function during "normal operating times" [14]), *recoverability* (in the event of an interruption or a failure, the data can be recovered and the desired state of the system is re-establish [14]), and *fault tolerance* (continue normal operation despite the presence of hardware or software faults [14]). Regarding relationships, adaptability of the system helps its modifiability because an adaptable system is one that is easily modifiable [18]. If a system is robust and has a good component of fault tolerance, then it will perform its tasks normally, leading to an increase of its availability [14]. If we define a set of criteria (functional- or performance-like) for the system to meet, we will help the system to function properly and as desired [13]. Finally, if we correctly maintain a system, in what concerns the correct usage of its components, it will lead to an increase of its reliability resulting in a long-lasting, healthier system [10]. Figure 2 expresses these decomposition and the relationships among features, once more allowing for configuration.

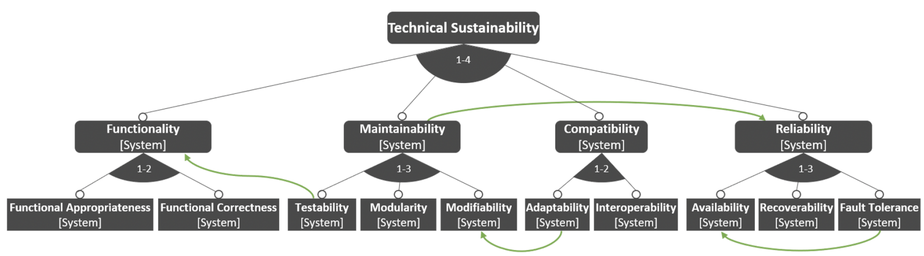

Fig. 2. Feature model for the **technical** dimension.

Inter-relationships Sustainability dimensions are inter-dependent [3], affecting each other positively or negatively and sharing some key requirements [10], [22], [27]. Here, we limit the discussion to the effects between the social and technical dimensions (even though the study also elicited economic and environmental properties). If a product has diverse functionalities and is reliable and provides interoperability, it may impact positively on the user satisfaction (social sustainability). Society can also have a positive impact on the technical side of a product by providing feedback and suggest new functionalities. The constant and ever evolving needs of the society can be seen as one of the main boosters of technology, which will ultimately result in better and more advanced products. Figure 5 depicts two of those relationships, for example, the help contribution between Functionality (of the system from the Technical Sustainability dimension) and Satisfaction (of the stakeholder from the social dimension).

3 Modeling Sustainability Catalog

Despite the feature model benefits, its constructors are not expressive enough to specify different types of properties (e.g., goals and qualities) as well as positive and negative level of effects among them. Also, as our plan for the near future is to refine those properties to the operationalization level to capture in the catalog possible solutions, a more expressive modeling notation is required. We chose the iStar framework as it provides the needed semantics and offers a good base for trade-off analysis [11].

We mapped the elements of the feature models (the source models) representing the notions of sustainability into elements of the iStar framework (the target model). Sustainability is composed of several dimensions and each dimension is an aggregate of several qualities that have effects on qualities of the same dimension and qualities of other dimensions. To obtain a cohesive catalog, we opted for mapping each dimension to a quality and sustainability to a root quality aggregating the various quality dimensions. Additionally, non-functional requirements identified in the mapping study, were also mapped to qualities dependent of the corresponding quality dimension. These were further refined in the iStar model, using the iStar links (e.g., refinement, contribution, qualification and neededBy). Each dimension catalog is, in fact, an SR (Strategic Rationale) iStar model that complies with the iStar 2.0 standards. We perceived the catalogs themselves as the actors of our models, and as the central and main element, the sustainability of each dimension (a quality), then was refined in various qualities. Finally, these main qualities relate to a set of other qualities, goals (and tasks), depending on the context, and can be further refined. However, we settled a four-level refinement as a maximum, to reduce the size of the whole catalog. The final step was to add possible resources needed to complete certain tasks (which we do not show here due to lack of space).

Lets take as an example the social dimension and some of its requirements (see Figure 3). The central quality is social sustainability. As discussed in Section 2.2, social sustainability relates to three different features: security, safety and satisfaction. These features, which in the iStar model are qualities, all link to the social sustainability via contribution links of type make. The third level focuses on the satisfaction (of the stakeholder), for instance. We know that satisfaction relates to the usefulness of the system, the stakeholder's trust and the fairness of the company. They are all qualities. Given each refinement, we should look for possible relationships. For example, the system's security helps stakeholders increase their trust on the system. Thus, such relationship is a help link contribution. We can further refine the usefulness, trust and fairness qualities. To assist this process, we applied known information about these refinements, which are presented in other NFR catalogs, such as [9]. Considering *usefulness* as an example, a useful system should accomplish its proposed functionalities, mapped into an iStar goal [14]. This goal (in a different color) can be named "accomplishment of proposed functionalities [system]". The final catalog is then obtained by creating links (e.g. contribution links) between model elements from different dimensions.

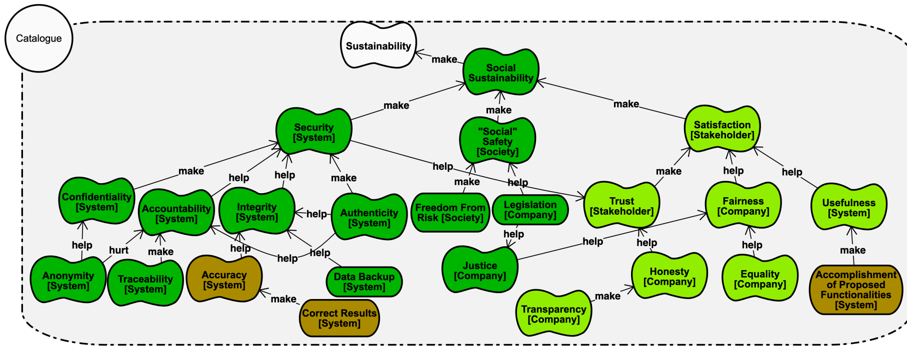

Fig. 3. Social dimension of the sustainability catalog.

4 Catalog Implementation and Tool Support

Our goal was to develop a reusable catalog. Thus, the tool should support configurability and modifiability. Configurability lets the user select a set of requirements across any combination of dimensions, obtaining only the sustainability requirements needed for her domain. Modifiability, on the other hand, lets the user modify the catalog according to his/her needs or knowledge. Also, the ability to save and load a custom catalog are basic functionalities. Finally, the tool includes functionalities to enhance the user experience, such as labels (e.g., labels for colors of model elements).

Among the existing tools supporting the iStar framework, we chose the open source piStar tool [26] because it is compliant with the iStar 2.0 standard, it is simple to use, produces valid and visually appealing iStar 2.0 models, and supports extendibility and customizability. We implemented three plugins for piStar[3]: configurability of the catalog; color label; and element label. The implementation uses JavaScript and HTML. The plugins, on the GUI, are clickable buttons that when clicked, perform the specified function. The configurability plugin is the main one and implements the configuration of the catalog, allowing the user to select the wanted features and getting the corresponding model. Even if we ideally want a fully sustainable system, in many situations the best we can do is to try to maximize a subset of dimensions by combining some properties of some dimensions to achieve partial sustainability.

The user has full freedom to choose the more suitable sustainability requirements for his domain and the catalog will shape accordingly. For instance, if we have a project that only focuses on two dimensions of sustainability, we can abstract from the other dimensions. We can configure and filter the catalog according to specific needs, selecting a checkbox associated with the main qualities of each dimension. The selected qualities will be displayed to the user. For in-

[3] These plugins are available from [1], in the *tool* tab.

stance, Figure 4 shows the configuration steps leading to the resulting catalog model after selecting all the qualities of social and technical dimensions.

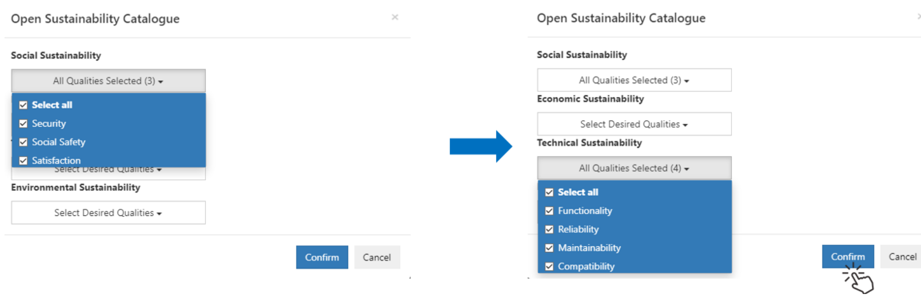

Fig. 4. Configuration steps.

Figure 5 shows the outcome of the configuration, a custom catalog according to the selected dimensions and respective features.

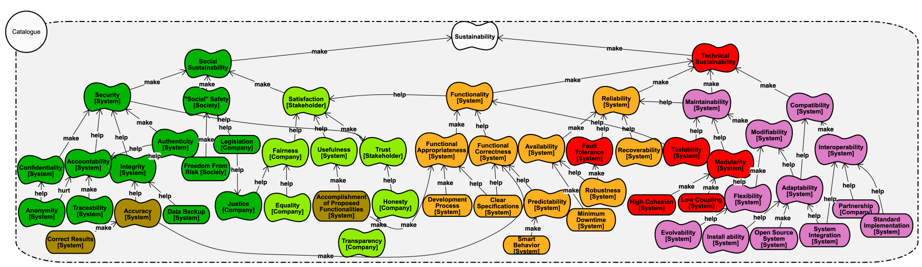

Fig. 5. Result of the Catalog Configuration.

The color and element labels facilitate the understanding of the catalog. Their purpose is purely for consulting information, so that one can check the color typology of the catalog (for the color label) or the semantics of each of its elements (for the elements label). Each element of a dimension has a respective color, so that the identification of a certain element would be easier to the user. A color for each dimension was defined. If an element relates to two or more dimensions, its color will result from the mixing of the colors of each dimension that it relates to. The catalog's color labels are shown in Figure 6.

5 Preliminary Evaluation

5.1 Instrument design and participants recruitment

We built a guide for the catalog and a questionnaire to perform an early assessment of the sustainability catalog. We evaluated the catalog in terms of clarity, readability, relevance, usefulness, and the extent to which it offers a general and

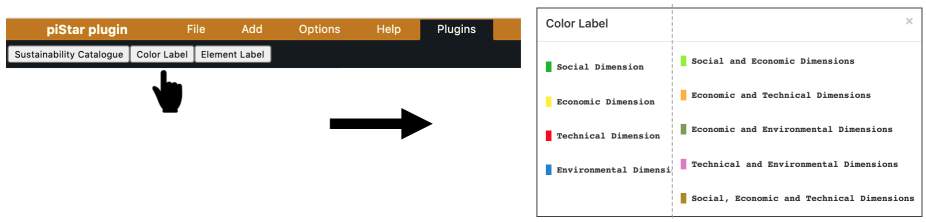

Fig. 6. Color label.

concise idea about sustainability requirements. We also assessed the guide for the catalog. We conducted this assessment through a survey composed of closed 5 points Likert-scaled questions. The survey included two additional open-end questions where participants commented on the most relevant or positive aspects of the catalog and identified opportunities for improvement. We collected basic demographic information on our participants. The guide, catalog, survey, and raw data included in this preliminary evaluation are available in this paper's companion site [1]. We chose the exact wording of the guide and the questions to make them accessible to novices and experts. We created the survey instrument with Google Forms. It has 5 sections: introduction, personal data, guide questions, catalog questions and open feedback questions. We collected respondents contacts to discern the experts from novices and make the survey results available to those who requested them. That said, we omit the contact information from the shared raw data to preserve respondents anonymity.

We recruited survey participants through convenience sampling, leveraging authors lists of related work papers on sustainability and personal contacts. This recruitment strategy allowed us to gather feedback from experts and novices with respect to sustainability. We invited 89 participants (41 experts and 49 novices) and received a total of 50 responses (16 experts and 34 novices) corresponding to a global answer rate of about 56% (34% for experts and 71% for novices). 26% of our participants hold a BSc, 34% have a MSc, and 40% hold a PhD.

5.2 Results

We organize the presentation of the results into the closed questions about the guide and the catalog, followed by the open questions about the catalog. For each question, we present the results concerning novices, experts and all of them combined. Figure 7 summarizes the answers collected with the questionnaire.

Guide questions The two first questions assess the *perceived usefulness* and *understandability* of the guide. Most novices and half of the experts expressed a positive perception about the guide's *usefulness*, while the remaining were neutral about it. Concerning *understandability*, 78% of the respondents expressed a positive perception, while 18% expressed a neutral one and the remaining 4% (1 novice and 1 expert) had a negative perception. One of our novice participants did not answer this question.

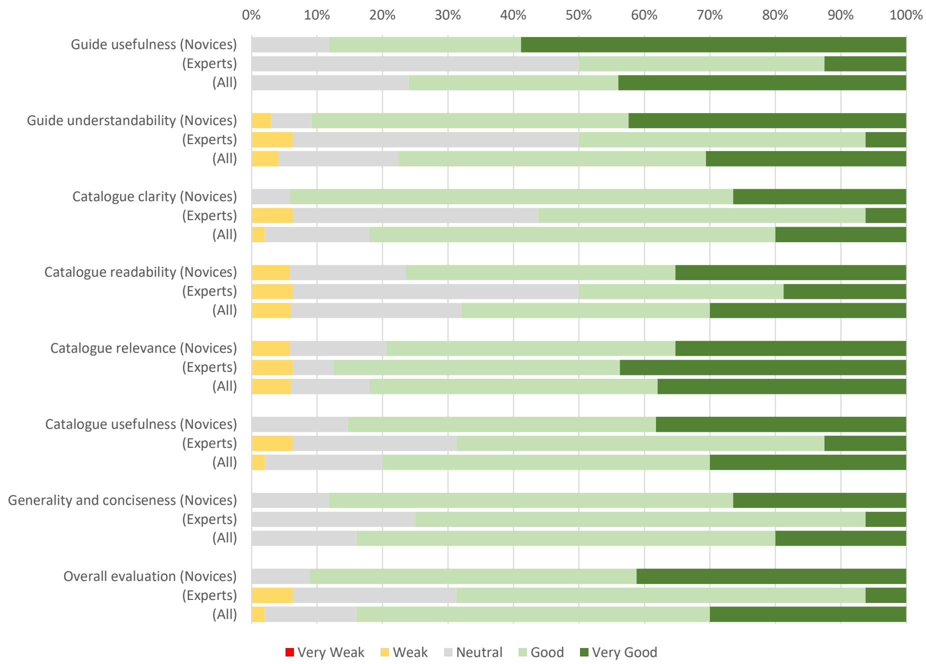

Fig. 7. Summary of the qualitative evaluation of the sustainability catalog.

Catalog questions The last 6 questions, summarized in Figure 7, assess the *clarity of the concepts in the catalog*, the *readability of the catalog*, the extent to which the *catalog is relevant*, *useful*, *general and concise* and, an overall evaluation of the catalog. The perceptions expressed by participants are positive, both for novices and experts, albeit novices have a more positive perception than experts in 5 of the questions. The exception is the perceived relevance of this catalog, which collected more positive answers from experts than from novices. The number of participants expressing negative feedback (*Weak*) was, at most, 3 (out of 50). Although the *Very Weak* category was also available as an alternative, our participants did not select it in any of the questions. The least positive perceptions concerned the catalog *readability*, where 68% of our respondents ranked it as *Very Good* (30%) or *Good* (38%), 26% were *Neutral*, and the remaining 6% considered it *Weak*.

We asked an additional closed question concerning the participant's willingness to use this catalog as a basis for future projects related to sustainability. 50% answered *Yes*, 48% *Perhaps*, and 2% (1 expert) answered *No*.

Open questions We collected feedback from participants on relevant or positive aspects, as well as points for improvement, comments and suggestions.

The most mentioned **relevant or positive aspects** were: *understandability*, *simplicity*, *configurability* and *completeness* of the catalog. Regarding *understandability*, some respondents enjoyed *"the visual representation of the concepts and the ability to see clear relationships"*, the *"perspective on inter-dependencies"* and the fact that *"it provides a general understanding of software sustainability requirements"*. In what concerns *simplicity*, participants liked *"the possibility to clearly visualize the interactions between the attributes and the goals in various different areas"*, as well as *"the organization in multiple layers and the support for fast-creation of sustainability concerns"*. Regarding *configurability* respondents mentioned the value of *"being able to be applied to nearly all projects"* and that *"(...) it can be tailored to user's need"*. Finally, in terms of *completeness*, participants referred *"the concept of a taxonomy that software developers can go to in order to make sure that they have addressed the most important sub-domains of sustainability"*.

About the **points for improvement**, the *color palette* and the *need for a use case or an example*, were the most cited ones. Respondents said *"maybe you could also use some colors for links since there may be positive and negative contributions"*, and *"you could use less saturated colours"*. One respondent suggests *"maybe some example could illustrate the benefit of the catalog"*, and *"it gives an impression of completeness and generality, while the focus should be on domains and examples"*. We agree that more examples are needed.

On **comments and suggestions** we had compliments about the importance and completeness of our work. One participant commented *"this is a good piece of work providing especially novice software requirement engineers or developers an understanding of sustainability in software development"*. We had some respondents asking if they could access the final work once finished, and various suggestions to make our work fully open-source and accessible to anyone.

6 Threats to validity

Internal validity. A threat to our survey is that we might not have asked the correct questions, or the questions might be ambiguous. To mitigate this, a segmentation of the questionnaire was performed so we clearly separate different evaluation topics and we were very careful on the wording and structure of the questions (validated among the authors). Furthermore, the participant may not have enough knowledge to answer the questions. Thereunto, we constructed a guide for our work. However, it may be too complex for the participant, or it may fail passing the adequate information. We made an effort to write the guide as succinct as possible and easily readable with the aid of visual illustrations.

Construct validity. Our catalog is based on the results obtaining from the mapping study. Therefore, its completeness and correctness depends on how well the mapping study was conducted. One threat of the mapping study is concerned with the search string not including all the relevant keywords. This was mitigated by validating it among the authors and also by performing an evaluation of the catalog with external participants through a questionnaire, where each question is directly related to an evaluation criterion (in a 1:1 mapping).

External validity. We performed a preliminary qualitative evaluation with 50 participants, including 16 experts. A larger sample of participants is required for an extended external validity. The participants' answers may be biased, since the answer is directly linked to their familiarity with the topic. To mitigate this issue we produced a guide document explaining the contents of the catalog.

Conclusion validity. Even though DBLP compiles a vast amount of publications from different sources covering the most relevant *fora* in Computer Science, we may have missed relevant information in our mapping study. To mitigate this, we performed backward and forward snowballing.

7 Related work

Some related works exist. We will summarize each and comment of the differences to our work. A sustainability design catalog to help developers and managers eliciting sustainability requirements is discussed by Oyedeji et al. [20]. It is based on the Karlskrona manifesto principles and the sustainability indicators. Positive and negative effects of software on the environment can be identified by using the approach. However, the inter-dependencies between dimensions are not covered. Paech et al. [21] present an approach to support the elicitation of sustainability requirements, by providing a checklist of general and IT-specific details for the sustainability dimensions and a checklist of general influences between the dimensions. Such checklists can be used to refine the requirements of a software application, in an iterative way, with sustainability aspects from the different dimensions. The use of checklists could be incorporated in our tool to configure our catalog. In Saputri and Lee [29], a goal-based approach is proposed to specify sustainability requirements, allowing the analysis of sustainability properties to evaluate impact and trade-off analysis of those requirements. The authors do not make use of a catalog to help the sustainability requirements identification. Brito et al. [5] define a model for sustainability concepts plus their relationships, as well as conflicts between sustainability dimensions or between those and other system requirements. For conflict management, a multi-criteria decision making method is used to rank, stakeholders and effects between requirements. This approach does not provide a catalog, but a multi-criteria method could be integrated into our work. In Penzenstadler et al. [23], an approach is proposed to identify successful sustainability interventions using leverage points (LPs), i.e., system locations where a change can impact significantly system-wide. Compared to ours, they do not provide a catalog to support their approach.

8 Conclusions

The sustainability catalog was defined based on the available published literature. It is domain independent and can be configured, using a web-based tool, to accommodate a subset of the whole set of properties (requirements and relationships). Even though this is a preliminary catalog, the results of the qualitative evaluation involving authors, teachers and students, are encouraging. The questionnaire was carefully thought to inquire about readability, interest and usefulness, and included a question about intention of use in future projects. A total of 50 respondents, from different ages, degrees, and academic experience, rated the catalog positively (rating 4.1 out of 5) and 98% of the participants stated they would use, or consider using, it in future projects.

We need to address the remaining sustainability dimensions: environmental, economic and individual. We collected some initial information for the first two and initiated their conceptualization. Also, the catalog's configurability needs to allow selection of refined qualities, not only the first level properties of each dimension. We plan to develop a sustainability web-application portal, and integrate a configured model with specific problem domain models. This web-application could then offer new adaptive labels, working sessions, and ease of look-ups, for example. Finally, we will apply the catalog to the UBike project[4], and hope to use it in several other cases studies. Offering a set of examples to illustrate the benefit of the catalog scenarios.

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