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# A social and technical sustainability requirements catalogue

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ABSTRACT

Climate change calls for action from all sectors of our global economy, including ICT. Therefore, it is important to change the way we develop software to address the challenges posed by sustainability. Our goal is to contribute with a reusable sustainability requirements catalogue that helps developers be aware of sustainability-related properties worth considering during software development. The information for this catalogue was gathered via a systematic mapping study, whose results were synthesised in feature models and then modelled using iStar for a more expressive and configurable representation. A qualitative evaluation of the catalogue's readability, interest, utility, and usefulness by 50 participants from the domain, showed that around 79% of the respondents found the catalogue "Good" or "Very Good". However, more than 5% of the expert participants found weaknesses regarding most of the evaluated questions and around 25% are neutral in their overall evaluation. This led us to evolve the initial version of the catalogue for the social and technical dimensions of sustainability to improve its completeness and usefulness. This is achieved by aligning the information gathered in the systematic mapping study with the well-established quality model of the ISO/IEC 25010:2011, as we expect most of the experts are familiar with those qualities and respective hierarchies. During this process, we found information that led us to propose two additional qualities that were not covered by the ISO standard: fairness and legislation. We applied this evolved version of the catalogue to the U-Bike project comparing the requirements elicited without the catalogue with those identified using the catalogue. The result suggests that new sustainability requirements were worth considering from a sustainability point of view, supporting the usefulness of the catalogue.

## 1. Introduction

The fight against climate change demands that all sectors of our global economy, including ICT, reduce their carbon footprint [1]. Therefore, sustainability should be considered key when developing modern applications. According to [2], sustainability implies *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*. This challenge calls for the synergy of *social equity*, *economic growth*, and *environmental preservation*, and consequently their effects on each other. These three dimensions have been integrated into other two complementary dimensions: an *individual* and a *technical* dimension [3]. Each dimension involves different aspects of a system and its context (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,

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sustainability-aware systems differ from other types of systems in that their functionality must explicitly consider the sustainability dimensions and balance the trade-offs between them.

Different works address sustainability in IT to different extents: an incremental perspective known as *Green IT* (e.g., [4,5]), a perspective where IT is the means to address sustainability known as *Green by IT* [6], and a more radical perspective that calls for a change in the way we live [7]. Here we follow the Green IT paradigm and see sustainability as *an emergent property of a software system* [8], where 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 particular work, we look at sustainability as a complex composite quality attribute, composed of five complex aggregates of quality attributes, one for each dimension, which, in turn, is composed of the quality attributes relevant to that dimension. Considering the complexity of sustainability and the lack of approaches to promote the identification and analysis of sustainability requirements and their integration with other system's requirements, reusable artefacts can contribute to tame this complexity.

Our goal is to develop a reusable sustainability catalogue that can be configured for different contexts and purposes. Our starting point was a systematic mapping study enriched with snowballing and manual search to gather, from the existing body of knowledge, the fundamental sustainability properties. The extracted concepts of each sustainability dimension were synthesised using feature models [9], to represent common and variable features (or concepts). In this paper, we focus on the social and technical sustainability dimensions.

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 [10], a goal-based requirements modelling 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 and dependencies. Finally, we implemented an extension to the piStar tool [11], offering configuration operations (e.g., add, select, project/filter, export) to extract subsets of the catalogue according to the problem domain needs and stakeholders' preferences.

We qualitatively evaluated the sustainability catalogue 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 catalogue fulfils the quality criteria. Nevertheless, the survey also revealed that more than 5% of the expert participants found some shortcomings regarding most of the evaluated questions and around 25% are neutral in their overall evaluation. Thus, to improve the catalogue's completeness and usefulness, we present an evolved version for the social and technical dimensions.

The evolved catalogue aligns the found information with the well-established quality model of the ISO/IEC 25010:2011 [12], as we expect most of the experts are familiar with its structure. This alignment promotes a common understanding of the considered quality attributes, as we adopt those as defined in the standard. During this process we identified two additional qualities that are not directly covered by the ISO standard: *fairness* [13] and *legislation* [14].

The evolved catalogue was applied to the IPBeja[1] branch of the U-Bike Portugal project.[2] This project promotes sustainable transportation in academic communities through the use of classic and electric bicycles, aiming at reducing primarily energy consumption and CO2 emissions. We then compared the elicited requirements of the current project with the requirements obtained with the help of the catalogue. The results support the usefulness of the catalogue as new sustainability requirements worth considering from a sustainability perspective were identified.

In summary, this paper extends our work in [15] with (i) an evolved version of the sustainability catalogue for the social and technical dimensions obtained via a consolidation with the ISO/IEC 25010:2011 quality model, and (ii) an application of the resulting catalogue to the IPBeja branch of the U-Bike Portugal project. An additional result of this consolidation process was the identification of two quality attributes which are not covered by the ISO/IEC quality model.

This paper is structured as follows. Section 2 summarises the results of a mapping study aiming at collecting sustainability concepts and relationships and synthesises the results in feature models, which are further mapped into iStar goal models. Section 3 discusses the results of the qualitative evaluation performed. Section 4 presents the new version of the catalogue aligned with the mentioned ISO/IEC 25010:2011 standard. Section 5 summaries the case study and offers a discussion with some takeaway messages. Section 6 presents related work, and, finally, Section 7 draws the conclusions and offers ideas for future work.

## 2. Towards a catalogue for sustainability

### *2.1. Data collection: a systematic mapping study*

To gather the necessary information to build a sustainability catalogue, we started by performing a mapping study that included steps of forward and backward snowballing and also a manual search. This section summarises the main results. Further details may be found in [16].

We followed the typical process suggested for systematic studies [17]: planning, conducting, and reporting. 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 analyses and presents the results.

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[2] https://www.u-bike.pt/sobre/

#### 2.1.1. Planning and conduction

We started by formulating the research questions and search string. The search string was run in the DBLP digital library, as it compiles a large number of publications from different sources (e.g., IEEEXplore, ACM, Science Direct, SpringerLink). The general research question was *What are the requirements that contribute or relate to sustainability?* 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 search strategy used two complementary search methods: automatic (in DBLP) and manual with snowballing. Snowballing was performed using the reference list of each selected primary study to identify additional potentially relevant studies, and also searched for publications referencing each particular primary study. The outcome of this study resulted in the initial version of our catalogue,[3] part of which was published in [15].

To select the relevant publications for analysis and data extraction, we defined the inclusion criteria (e.g., conference, journal, or workshop papers written in English and published after 1987,[4] full text available, relevant to the research question) and also the exclusion criteria (e.g., duplicates, informal documents, and documents violating the inclusion criteria). Running the search string on DBLP retrieved 169 candidate studies. First, papers were selected based on title and abstract reading, and then the selected studies were fully read, resulting in 8 papers [13,18–24] for analysis. After snowballing, 5 more articles [3,4,14,25,26] were selected, totalising 13 papers for data extraction.

#### 2.1.2. Synthesis of results and reporting

The primary studies discussing software sustainability and its importance [18–22], models and frameworks [3,23,25], requirements and sustainability relationships [24] 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 [3,22]. Thus, a sustainable product should balance the goals of these dimensions. This balance is hard to achieve 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 of which are also available in [27–29]).

The synthesis of the results is expressed in a feature model [9], 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 [20]. It can also be seen as the well-being of humans living in such a society [26]. This dimension is related to notions such as honesty, transparency, communication, security, and safety [20]. 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 organisation), and *Fairness* (regarding equality and honesty) [24,30]. Security is an important requirement of the social dimension [24], as systems' data and information cannot be compromised, hence divided into *Confidentiality*, *Authenticity*, *Integrity*, and *Accountability* [12]. Safety is divided into *Freedom from Risk* (i.e., mitigation of the potential risk to people [30]) [24] and *Legislation* [14] (compliance with the laws and regulations). A few relationships were also elicited. In particular, Security increases the Trust of stakeholders (represented by a *requires* relationship), since a secure system is one that inspires trust in the user [30]. A system's Authenticity requires both its Integrity and its Accountability [12]. However, Confidentiality may be prejudicial for Accountability [12] since it could be harder to trace the origin of the data, due to possible anonymity. The feature model in Fig. 1 expresses the decomposition of the dimension and the various relationships among features, where optional operators allow flexibility to the decision maker.

*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 [20], 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) [24]. 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 [12]), *Modularity* (components may be separated and recombined, often with the benefit of flexibility and variety in use, with minimal impact on other components [12,31]), and *Modifiability* (changes to a software system can be developed and deployed efficiently and cost effectively [12]). Compatibility is divided into *Adaptability* (ability to adapt to constant changes) and *Interoperability* (ability to couple or facilitate interface with other systems). Finally, Reliability [20] is divided into *Availability* (the system is able to function during "normal operating times" [12]), *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 [12]), and *Fault Tolerance* (continue normal operation despite the presence of hardware or software faults [12]). Regarding relationships, Adaptability of the system helps its Modifiability because an adaptable system is one that is easily modifiable [32]. If a system is robust and has a good component of fault tolerance, then it will perform its tasks normally, leading to an increase in its Availability [12]. 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 [30]. Finally, if we correctly maintain a system, in what concerns the correct usage of its components, it will lead to an increase in its Reliability resulting in a long-lasting, healthier system [24]. Fig. 2 expresses these decompositions and relationships among features, once more allowing for configuration.

3 https://sites.google.com/fct.unl.pt/sustreqscatalogue/

4 This is the publication year of the Brundtland report, which we consider to be a major alert for the dangers of an unsustainable world.

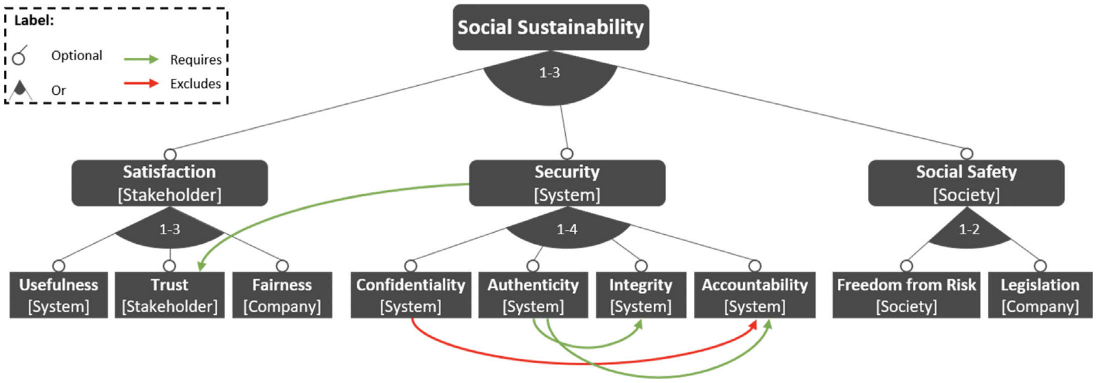


**Fig. 1.** Feature model for the **social** dimension.

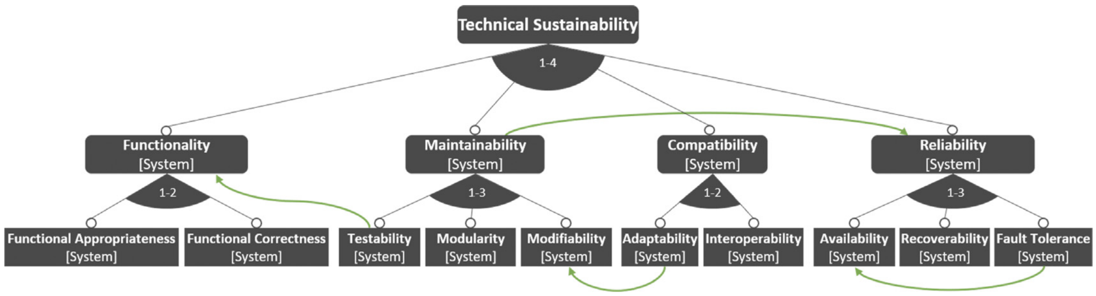


**Fig. 2.** Feature model for the **technical** dimension.

*Inter-relationships.* Sustainability dimensions are inter-dependent [20], affecting each other positively or negatively and sharing some key requirements [4,14,24]. 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 user satisfaction (social sustainability). Society can also have a positive impact on the technical side of a product by providing feedback and suggesting new functionalities. The constant and ever-evolving needs of society can be seen as one of the main boosters of technology, which will ultimately result in better and more advanced products. Fig. 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).

### 2.2. Modelling the sustainability catalogue

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 the positive and negative level of effects among them. Also, as our plan for the near future is to refine those properties to the operationalisation level to capture in the catalogue possible solutions, a more expressive modelling notation is required. We chose the iStar framework, as it provides the needed semantics and offers a good base for trade-off analysis [10].

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). Each dimension of sustainability is an aggregate of several qualities that have effects on qualities of the same dimension and on qualities of other dimensions. To obtain a cohesive catalogue, we opted for mapping each dimension to a "quality" and sustainability to a "root" quality aggregating the various quality dimensions. Additionally, quality attributes identified in the mapping study were also mapped to qualities dependent on 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 catalogue can be expanded to be a fully-detailed SR (Strategic Rationale) iStar model.

Let us take as an example the social dimension and some of its requirements (see Fig. 3). The central quality is Social Sustainability. As discussed in Section 2.1.2, Social Sustainability relates to three different features: Security, Safety, and Satisfaction. These features, which in the iStar model are qualities, all link to 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 organisation (or 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 in the system. Thus, such a 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 catalogues, such as [27]. Considering

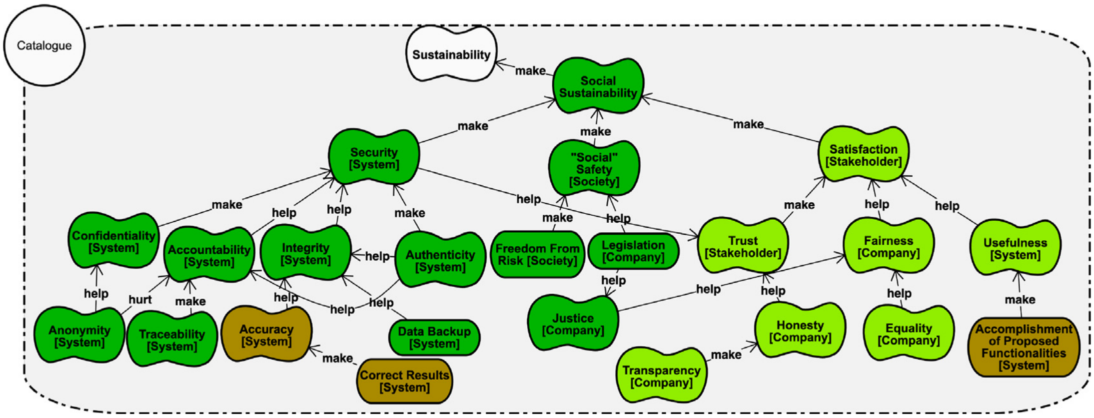


**Fig. 3.** Social dimension of the sustainability catalogue.

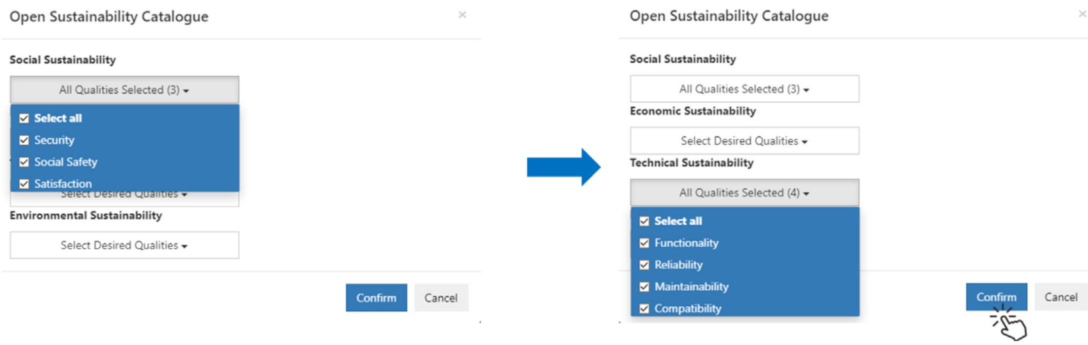


**Fig. 4.** Configuration steps.

*Usefulness* as an example, a useful system should accomplish its proposed functionalities, mapped into an iStar goal [12]. This goal (in a different colour) can be named "accomplishment of proposed functionalities [system]". The final catalogue is then obtained by creating links (e.g. contribution links) between model elements from different dimensions.

### 2.3. Catalogue implementation and tool support

Our goal was to develop a reusable catalogue. 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 catalogue according to his/her needs or knowledge. Also, saving and loading a custom catalogue are basic functionalities. Finally, the tool includes functionalities to enhance the user experience, such as labels (e.g., labels for colours of model elements).

Among the existing tools supporting the iStar framework, we chose the open source piStar tool [11] 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 extensibility and customizability. We implemented three plugins for piStar[5]: configurability of the catalogue; colour 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 catalogue, allowing the user to select the wanted features and get the corresponding model. Even if we ideally want a fully sustainable system, in many situations the best we can do is to try to maximise 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 tool allows the configuration of the catalogue producing a filtered instance with the selected dimensions and qualities. The configuration step is performed by selecting the checkboxes associated with the main qualities of each dimension. The selected qualities will be displayed to the user. For instance, Fig. 4 shows the configuration steps leading to the resulting catalogue model after selecting all the qualities of social and technical dimensions.

Fig. 5 shows the outcome of the configuration, a custom catalogue according to the selected dimensions and respective qualities.

[5] These plugins are available from [33], in the *tool* tab.

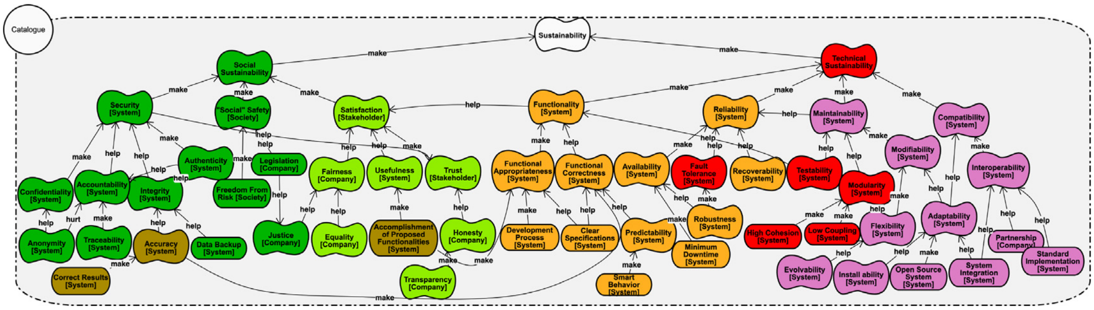


**Fig. 5.** Result of the catalogue Configuration.

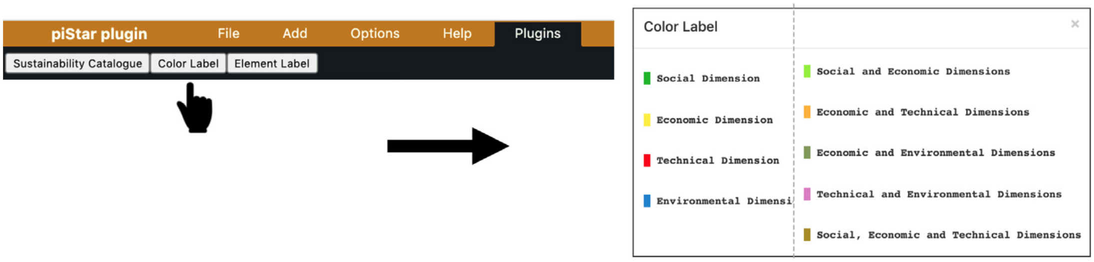


**Fig. 6.** Colour label.

The colour and element labels facilitate the understanding of the catalogue. Their purpose is purely informative; one can check the colour typology of the catalogue (for the colour label) or the semantics of each of its elements (for the elements' label). Each dimension has a colour, and each element of that dimension shares that same colour to facilitate detection. If an element relates to two or more dimensions, its colour will result from the mixing the colours of each dimension that it relates to. The catalogue's colour labels are shown in Fig. 6.

## 3. Preliminary evaluation

### 3.1. Instrument design and participants recruitment

We built a guide for the catalogue and a questionnaire to perform an early assessment of the sustainability catalogue. We evaluated the catalogue in terms of clarity, readability, relevance, usefulness, and the extent to which it offers a general and concise idea about sustainability requirements. We also assessed the guide for the catalogue. We conducted this assessment through a survey composed of closed 5-points Likert-scaled questions. The survey included two additional open-ended questions where participants commented on the most relevant or positive aspects of the catalogue and identified opportunities for improvement. We collected basic demographic information on our participants. The guide, catalogue, survey, and raw data included in this preliminary evaluation are available in this paper's companion site [33]. 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, catalogue 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 an MSc, and 40% hold a PhD.

### 3.2. Results

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

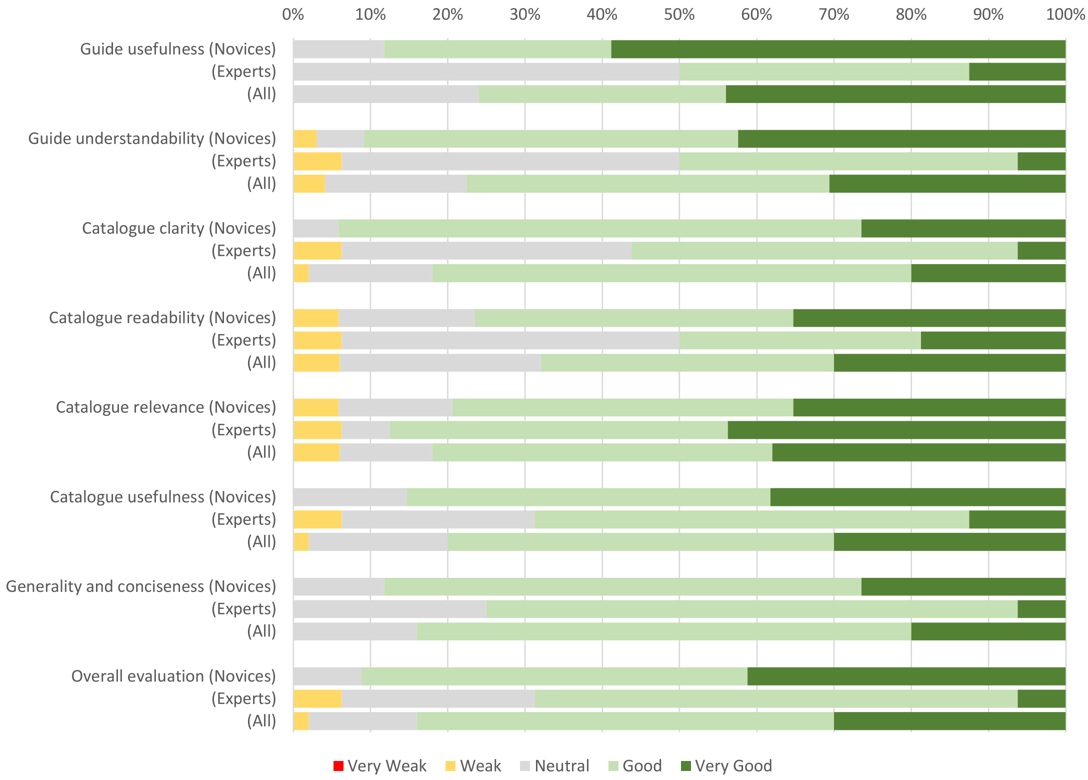


**Fig. 7.** Summary of the qualitative evaluation of the sustainability catalogue.

*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.

*Catalogue questions.* The last 6 questions, summarised in Fig. 7, assess the *clarity of the concepts in the catalogue*, the *readability of the catalogue*, the extent to which the *catalogue is relevant*, *useful*, *general and concise* and, an overall evaluation of the catalogue. 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 catalogue, 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 catalogue *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 catalogue 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 catalogue. 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 visualise the interactions between the attributes and the goals in various different areas"*, as well as *"the organisation 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 that *"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 *colour palette* and the *need for a use case or an example*, were the most cited ones. Respondents said *"maybe you could also use some colours 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 catalogue"*, 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.

Regarding **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.

### 3.3. 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 with the wording and structure of the questions (validated among the authors). As the participant may not have enough knowledge to answer the questions, we constructed a guide, and we made an effort to write it succinct and easily readable with the aid of visual illustrations.

*Construct validity.* Our catalogue is based on the results obtained from the mapping study. Therefore, its completeness and correctness depend 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 catalogue 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 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 catalogue.

*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.

### 3.4. Points of improvement

Even though the results seem quite positive overall, a closer look shows that more than 5% of the expert participants found weaknesses regarding most of the evaluated questions, and around 25% are neutral in their overall evaluation. With this preliminary evaluation, we believe we can improve the clarity, readability, usefulness, completeness, and conciseness of the catalogue by:

- focusing on the catalogue in the second-refinement level, leaving further refinements and operationalisations of the quality attributes to the users of the catalogue, in the context of their projects;
- aligning the found information with the well-established quality model of the ISO/IEC 25010:2011 [12], as we expect most of the experts are familiar with those qualities and respective hierarchy;
- complementing the found information with additional qualities that are becoming more relevant in a world we need more inclusive, and which are not included in the ISO standard.

## 4. Evolved catalogue

Given the interpretation of the results of the preliminary evaluation, this section presents an evolved version of the catalogue to address the limitations discussed in Section 3.4.

### 4.1. Catalogue consolidation

The consolidation of the catalogue is done in two ways: by comparison with an integration of the ISO/IEC 25010 standard, and by opening room for handling Human Values in the future, starting by integrating the Fairness attribute, which we considered relevant during our mapping study. In the future, we deem other attributes might be integrated as well.

*Comparison with the ISO/IEC 25010 standard.* The previous version of the catalogue did not incorporate all the qualities and structure of the standard, since our goal was to be, as much as possible, loyal to the majority of the selected primary studies. However, as we expect, most of the experts are familiar with the qualities and structure of the ISO/IEC 25010 standard. Given that, we performed a thorough comparison of the attributes in the catalogue and those in the standard. This led us to the following changes:

- include additional attributes in the catalogue, for completeness (e.g. those marked in blue in Figs. 8 and 9);
- change (some) attribute names (e.g., Functionality to Functional Suitability in the technical dimension), to be in accordance with the standard;
- move attributes in the hierarchy (e.g., Safety), marked in orange in Figs. 8 and 9;
- maintain the Fairness attribute, moving it to a new position in the hierarchy, even though it does not exist in the ISO/IEC standard, marked in green in Fig. 8;
- add the Legislation attribute, which is also not directly part of the standard as this was identified as a relevant attribute in [14], also marked in green in Fig. 8.

Finally, the distribution of the qualities among the various dimensions was performed based on the distribution proposed in [24].

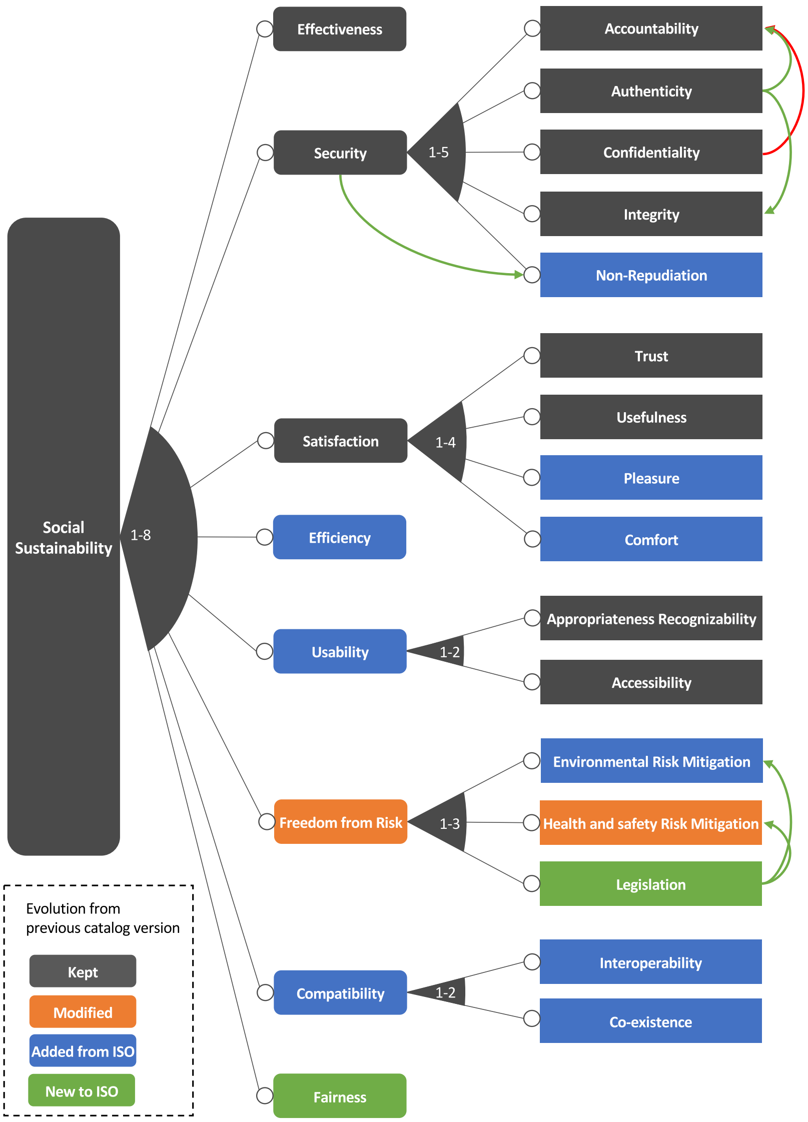


**Fig. 8.** New Feature Model for the **social** dimension.

*Beyond the ISO/IEC 25010 standard.* We identified two requirements, Fairness [13] and Legislation [14], as relevant for our catalogue, though they are not part of the ISO/IEC standard. Nonetheless, we believe it is important to consider requirements pertaining to Human Values [34] in future work, given their relevance in Computer Science [35,36].

The Oxford dictionary defines Fairness as *the quality of treating people equally or in a way that is reasonable*. Inclusion and non-discrimination are increasingly relevant in software systems, particularly because software is becoming more and more used for decision-making. Therefore, it is important that a software system is able to contemplate fairness in its use. For example, a decision-making system should automatically measure discrimination (e.g., to ensure fairness in software crowdsourcing platforms). Fairness is considered important in software by other authors [37–40].

Also, in the context of the Social Dimension, Legislation might influence software requirements or empower software to pursue sustainable practices [14,41]. According to Sommerville, there are *legislative requirements that must be followed to ensure that the system operates within the law* [42]. In our case, this makes sense since, for example, GDPR legislation protects personal information, i.e., the individuals' rights must be appropriately protected to reduce potential risks to the users (Freedom from Risk).

### 4.2. Consolidated feature models

All the above-discussed changes have been integrated into the feature model for the social dimension depicted in Fig. 8 and for the technical dimension in Fig. 9.

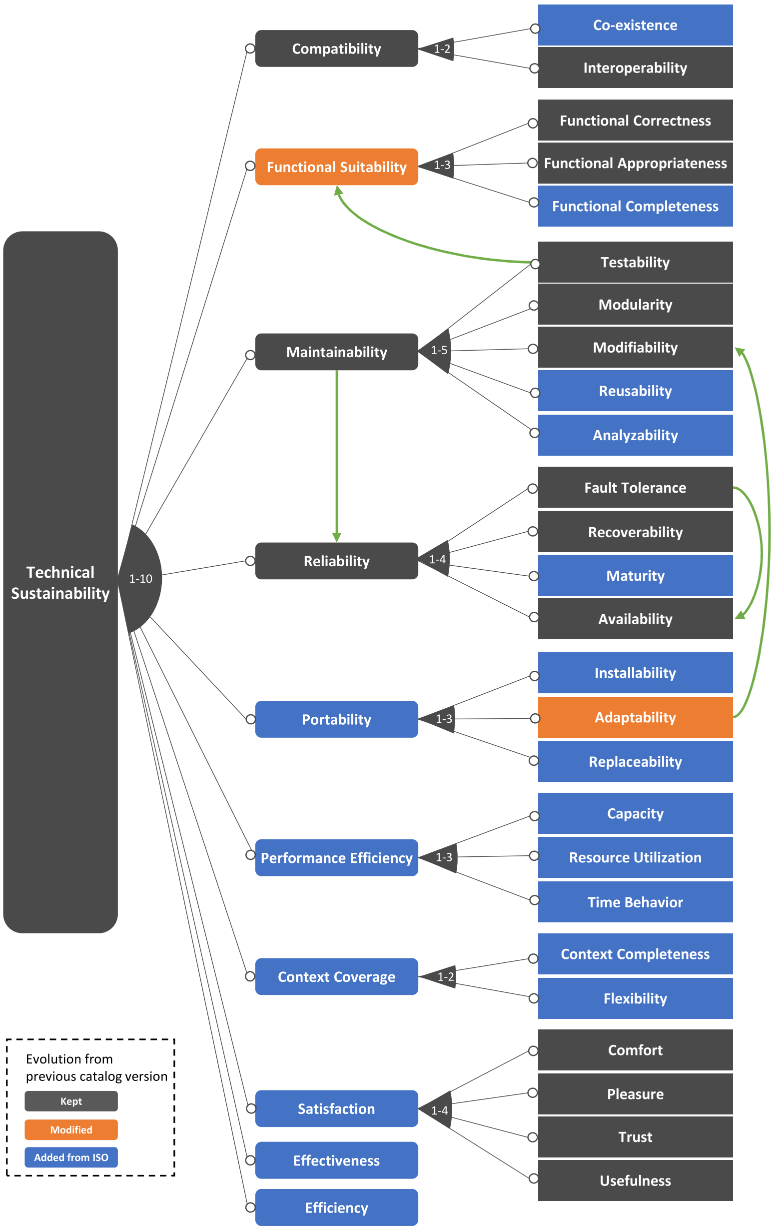


**Fig. 9.** New Feature Model for the **technical** dimension.

## 5. U-Bike Portugal project

In this section, we will apply the catalogue to a branch of the U-Bike project [43]. We start by describing the project followed by the elicitation of the main goals and qualities. Next, we identify the sustainability quality requirements and validate those with the catalogue. Finally, we discuss the main takeaway messages.

As the sustainability catalogue was unavailable at the time the U-Bike project was developed, we will base this discussion on illustrating the value of the catalogue to complement the techniques chosen for the elicitation process. First, we will discuss the goals and qualities addressed in the project and then we compare the resulting qualities with those we would select from the sustainability catalogue following the strategy discussed in Section 5.3.

### 5.1. U-Bike IPBeja project description

The U-Bike Portugal[6] project provides classic and electric bicycles to the academic community (e.g., students, teachers, and academic staff) in order to encourage more sustainable urban transportation. The bikes are entrusted to the academic community for long-term use, leading to the regular use of this means of transport. This project aims primarily at reducing energy consumption and CO2 emissions in academic cities. It is coordinated by the Institute of Mobility and Transport (IMT) and is co-funded by the Portugal 2020 program, particularly through POSEUR (Operational Programme for Sustainability and Efficient Use of Resources).[7]

Here we will focus on the U-Bike IPBeja, the branch of the project for the Polytechnic Institute of Beja. Beja is a small city in the southern part of Portugal that also provides infrastructure for public transportation and electric vehicles. Beyond the goals of the U-Bike Portugal, the U-Bike IPBeja also focus on promoting healthy physical activity. This pilot project provides Beja's academic community with 120 conventional and 80 electric bicycles. Even though any member of the academic community can apply to use the bikes, the candidates chosen first are those driving combustion engine vehicles and among these, those driving the most pollutant ones (e.g., diesel engines).

### 5.2. Requirements elicitation: goals and qualities

This section summarises the high-level requirements expressed through goals and quality attributes collected during the elicitation process performed by the company hired to develop the project. This process started with a meeting with five IPBeja representatives, and then three focus groups (one with students, another with academic staff, and another with non-academic staff), each with an average of 6 people. The meetings were all driven by the same questionnaire and guide. The questionnaire was composed of three sections: questions about hardware (e.g., type of mobile phones), questions about software (e.g., type of mobile operating system), and questions about infrastructure and conditions to have a bike under their responsibility (e.g., parking space).

At least two members of the project team participated in the meetings to ask prior defined questions and register the answers provided. More meetings were held in the later stages of the project to validate the identified requirements and discuss the proposed solution (prior to implementation). Here we will only focus on the requirements elicitation activity. The sources for the requirements listed in the next sections are the notes taken during the meetings, the answers to the questionnaire, and documentation from U-Bike Portugal project published by IMT and POSEUR.

We used a goal-based approach to identify actors, goals, and qualities related to the intended system.

#### 5.2.1. Actors

The actors related to this problem domain can be classified into primary (those initiating actions in the system) and secondary (those contributing to actions initiated by primary actors). The primary actors are end-users of the academic community (students, teachers, academic and non-academic staff), and the project owner (IPBeja). The secondary actors are the funding agencies (IMT, POSEUR), Beja's city hall, medical experts (nurses and doctors) from the School of Health of IPBeja, telecommunication operators, and product and service suppliers (bike sellers, and smart locks sellers).

As mentioned previously, the bike end-users were selected from the set of applications submitted by the academic community.

#### 5.2.2. Goals

We focus on the basic set of goals only. The first goal to consider handles the selection of candidates (Candidate selected), which results in a contract between the end-user and IPBeja, signed by both parties. End-users can renew their contract when it ends (Contract renewed). End-users have an associated profile to manage (Profile managed), which they need to manage their trips (Trip managed), bikes (Bike managed), and smart locks (Lock managed).

IPBeja needs to report on bicycle usage, routes, and CO2 emissions to funding agencies (Report managed). IPBeja also needs to manage the bicycle fleet (Fleet managed), and the users (User managed).

#### 5.2.3. Qualities

The main qualities that were identified during the elicitation meetings with our actors were:

- Time Behaviour: real-time trip and bicycle location data is collected;
- Availability: the system must be available 24/7;
- Usability: it should be easy to use and accessible by all academic users;
- Confidentiality: respect the General Data Protection Regulation (GDPR);
- Interoperability: different systems can connect and exchange information with one another.

[6] https://www.u-bike.pt/sobre/

[7] https://poseur.portugal2020.pt/pt/candidatura-detalhe/

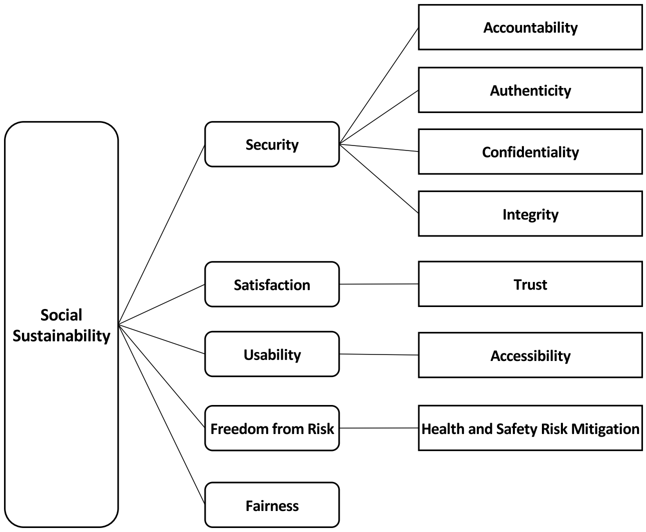


**Fig. 10.** U-Bike selected qualities from the social dimension catalogue.

### 5.3. Requirements with sustainability in mind

The U-Bike Portugal project aims to provide concrete actions to encourage the adoption of more sustainable mobility habits in academic communities of higher education and to impact positively on the reduction of greenhouse gas emissions in various cities in Portugal. Therefore, at its core, the project was created with the environmental dimension of sustainability in mind. In fact, in the last decade, several municipalities in Portugal have been restricting access to combustion engine vehicles to several city areas. This has led to converting existing road lanes into bike lanes. Loved by some and argued by others, such decisions have been made in the political sphere, hence harming the potential positive impact on society (at least in the short-medium term). But from the U-Bike perspective, we believe the project has several positive effects on society, such as fairness in accessing the system. This project also aims at promoting good health indicators (e.g., decrease cholesterol) in users (individual dimension) as well as offering them cheap mobility transportation and, in the long run, hopefully also saving costs to the national health system or promoting the appearance of new services (economic dimension). As per the technical dimension, there are several qualities to consider, such as efficient use of the users' mobile resources. The social and technical dimensions will be discussed next in the context of the project.

As the original stakeholders of the U-Bike project were no longer available, we faced the difficulty of deciding which qualities from the catalogue should be chosen. Instead of making this selection considering our preferences, we opted for using the most voted qualities from the empirical study in [24] for the social dimension (Confidentiality, Authenticity, Trust, and Health and Safety risk mitigation) and the technical dimension (Functional Correctness, Interoperability, Availability, and Functional Appropriateness). The end result includes these qualities, plus a few others we consider relevant for the problem domain, and also the ones, if not yet considered, implemented in the current project (Section 5.2.3). This is discussed in the next two subsections.

#### 5.3.1. Configuring the social sustainability catalogue

Regarding *social sustainability properties*, we selected Confidentiality and Authenticity (from Security), Trust (from Satisfaction), and Health and safety risk mitigation (from Freedom from risk). Given the dependencies in the feature model (see Fig. 8), by selecting Security we should also select Accountability and Integrity. Such a decision leads to a conflicting situation where, by selecting Confidentiality, we should exclude Accountability (red dependency in the feature model). Given the legal constraints of the GDPR, we propose to maximise Confidentiality over Accountability, but still keep Accountability to ensure accountable usage of the bikes, for example. Additionally to the most voted qualities in [24], and given its importance in a world increasingly aware of the importance of Human Values [35,36], we would also choose Fairness, very much related to not excluding users with less sophisticated smartphones or guaranteeing a fair selection process. Next, by looking at the qualities currently addressed in the project, we realise that, from the qualities listed in Section 5.2.3, Usability and Confidentiality should be considered. As Confidentiality is part of Security (already selected) we do not need to add it. Regarding Usability, the project was concerned with Accessibility. The resulting feature model from the configuration (or selection) process is depicted in Fig. 10.

#### 5.3.2. Configuring the technical sustainability catalogue

Concerning *technical sustainability properties* (see Fig. 9), we selected Functional Correctness and Functional Appropriateness (from Functional Suitability), Interoperability (from Compatibility), and Availability (from Reliability). By analysing the catalogue further and based on our knowledge from the domain, we find also relevant for this project Fault tolerance which reinforces Availability (according to the "requires" dependency in the catalogue) to guarantee constant collection of the data associated

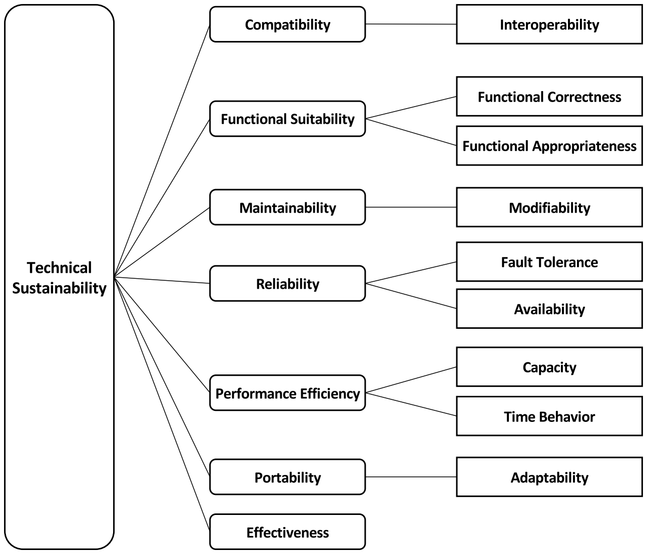


**Fig. 11.** Selected qualities of technical dimension catalogue for the U-Bike example.

with usage, Modifiability (from Maintainability) to better accommodate new requirements/features, and also Adaptability (from Portability) since the system should be prepared to adapt to evolving (or different) hardware or software. Also, Capacity (from Performance Efficiency) is important as users' mobile devices may have limited resources, and finally, Effectiveness is essential to keep the stakeholders' interest in using the system. Analogously to what we did concerning the social dimension, we should also consolidate this list of qualities with those actually addressed in the U-Bike project. In this case, we found that the current project development was also concerned with Time behaviour (from Performance Efficiency) to facilitate localising the bicycles, for example. The result of configuring the feature model catalogue is depicted in Fig. 11

*5.4. Discussion*

*Insights from the use of the catalogue.* Using the catalogue facilitates the work of the software engineer as it provides base information about sustainability that can be consulted and reused in several contexts, thus speeding up the development process as a whole. Reusing relevant sustainability qualities, prevents the target system from missing relevant concerns. When these are identified early in the development, trade-offs can be negotiated with relevant stakeholders, allowing for early strategic decisions. Such systematic identification of sustainability qualities results in more sustainable systems. Our catalogue covers the most relevant aspects of the social and technical dimensions, while also being aligned with the well-known ISO/IEC 25010 standard.

*Eliciting requirements with sustainability in mind.* Eliciting requirements with sustainability in mind is difficult, due to the inherent complexity of the latter. The lessons learned from our experience can be summarised in three major points:

- **systems thinking** [44], as opposed to computational thinking, helped us to look at and discuss the reality of the U-Bike project in the context of the city of Beja, and to better understand how the system may influence the quality of the lives affected by it. This is fundamental when thinking about the various dimensions of sustainability, particularly the individual and the social dimensions;
- **critical thinking** [45] forced us raising questions all the time to find relevant information, and challenged us to defy our beliefs and be aware of subsequent implications;
- **holistic process** led us to think about all the sustainability dimensions, meaning that the interests, values, ways of thinking, experiences, and skills of non-primary stakeholders in the project should be considered.

*Limitations.* When thinking about sustainability in general, and qualities in particular, it is very tempting to select them all, which is not realistic in terms of the project budget and even the knowledge of the team. In fact, the final decision of the qualities to integrate into the project will depend on the budget (as quality attributes are expensive to implement), schedule (even if the budget exists, there might not be enough time), and knowledge (sustainability is still an emerging topic in Computing Science S and Information Technology curricula) of the team. In this case, we did not have access to the whole set of major stakeholders to help in the choice of relevant sustainability-related qualities. However, one of the authors is a member of the project owner team, helping in the decision-making. Nonetheless, one needs to define a list of criteria to help select the relevant sustainability requirements, which are certainly dependent on the context involved, such as problem domain, project resources (time, financial, and team skills), and project owner and other major stakeholders. In general, average stakeholders might not have enough sustainability competencies. Eventually, some training in the area will be necessary. Therefore, more work is needed to integrate effectively the catalogue's sustainability quality requirements with other requirements approaches (e.g., scenario-based, goal-oriented).

## 6. Related work

Different methods to study sustainability in requirements engineering have been proposed, from goal-based approaches to catalogues and metamodels. For instance, a sustainability design catalogue, to help developers and managers elicit sustainability requirements, is discussed by Oyedeji et al. [26]. This work is based on the Karlskrona manifesto principles and sustainability indicators. It helps identify positive and negative effects of software on the environment. However, the inter-dependencies between dimensions are not covered.

Paech et al. [46] present an approach to support the elicitation of sustainability requirements, by providing a checklist of general and IT-specific details for the sustainability dimensions as well as a checklist of general influences between the dimensions. Such checklists can be used to attractively refine the requirements of a software application with sustainability aspects from the different dimensions. The use of checklists could be incorporated into our tool to configure our catalogue.

Saputri and Lee [47] propose a goal-based approach to specify sustainability requirements, allowing the analysis of sustainability properties to evaluate the impact and trade-off analysis of those requirements. The authors do not make use of a catalogue to help with the sustainability requirements identification.

Brito et al. [48] 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 catalogue, but a multi-criteria method could be integrated into our work.

Penzenstadler et al. [49] propose an approach to identify successful sustainability interventions using leverage points (LPs), i.e., system locations where a change can impact on the system significantly. Compared to ours, they do not provide a catalogue to support their approach.

In this paper, we extend our previous work [15] on a reusable sustainability software requirements catalogue that can be configured to different contexts. In the present paper, we present an evolved version of the catalogue obtained by consolidating it with the ISO/IEC 25010 standard, propose two new qualities to be added to the standard, and report on the application of the catalogue to the U-Bike IPBeja project.

## 7. Conclusions

The initial version of the sustainability catalogue [15] 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). A qualitative evaluation involving authors, teachers, and students was performed, where the questionnaire was carefully thought to inquire about readability, interest, and usefulness, and included a question about the intention of use in future projects. A total of 50 respondents, of different ages, degrees, and academic experiences, rated the catalogue positively (rating 4.1 out of 5) and 98% of the participants stated they would use, or consider using, it in future projects. Although the overall results were encouraging, 5% of the experts pointed out weaknesses, while the other 25% were neutral. Having these results as an opportunity for enhancement, we decided to evolve to a new version of the catalogue to improve usefulness and completeness, by aligning it with the ISO/IEC 25010:2011 standard, since experts are more likely to be familiar with that standard. While extending the catalogue we realised that two qualities initially identified and that we find very relevant – Fairness and Legislation – were not part of the ISO/IEC standard. Finally, we applied this new version of the catalogue to a real project (U-Bike) and concluded that the catalogue helped elicit additional sustainability requirements, compared to the project's initial list of requirements.

One of the next steps in our future work is to update the piStar prototype tool for the evolved catalogue, to reflect the current feature models in iStar for the social and technical sustainability dimensions. Also, we need to address the remaining sustainability dimensions: environmental, economic and individual. We collected some initial information for the first two and initiated their conceptualisation. Also, the catalogue's configurability needs to allow the selection of refined qualities, not only the first-level properties of each dimension. Our plan is 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. We will apply the catalogue with the other dimensions to the U-Bike project and hope to use it in several other cases studies, collecting a set of examples to illustrate the benefit of the catalogue scenarios. We will leverage the experience of applying this catalogue to diverse domains to propose a general method on how this catalogue can be integrated into the Requirements Engineering process. Finally, similarly to what we did for Fairness and Legislation, we also intend to extend the catalogue to address other Human Value concerns that are relevant to sustainability.

## CRediT authorship contribution statement

**Ana Moreira:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **João Araújo:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Catarina Gralha:** Methodology, Writing – review & editing. **Miguel Goulão:** Methodology, Validation, Formal analysis, Investigation, Writing – review & editing, Visualization. **Isabel Sofia Brito:** Methodology, Investigation, Writing – review & editing. **Diogo Albuquerque:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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