Community-Driven Standardization of Technical Documentation of Open-Source Hardware

Exposé

Martin Häuer

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Contents

Chapter 1

Introduction and Scope

1.1 Introduction

Over the past century, de jure standardization, established by national and international standards bodies, has become a cornerstone of modern industrial societies.
These organizations provide a robust and structured framework for developing representative consensus – meaning that technical standards reflect a broadly agreed-upon understanding across all relevant interested groups, capturing the state of the art in a formal and reliable manner ("DIN EN 45020:2007-03" n.d., 1.5).
Due to their representativeness (and the respective mandate), de jure standards can be directly referenced in legislation, thereby becoming part of public regulation ("DIN 820-1:2022-12" n.d., 5.1, "Normungsvertrag"; "New Legislative Framework - European Commission" n.d.). Consensus within this framework creates an environment where all actors are mutually dependent, preventing any single party from dominating the process ("DIN 820-1:2022-12" n.d., 5.3). This balance is further reinforced by the involvement and information of the general public ("DIN 820-1:2022-12" n.d., 7.4).

National standards bodies may join umbrella organizations to avoid duplicate efforts and competing standards across member states. At the international level, these are the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). Because all participating standards bodies are bound to the ISO/IEC Directives (*ISO/IEC Directives, Part 1* 2024), any de jure standard developed under this framework can, in general, be endorsed by any other participating standards body. Today, nearly all sovereign states worldwide are ISO members via their national standards body[1]. Any stakeholder in those states can, in principle, participate in international de jure standardization projects via their respective national standards body.

[1] 174 ISO member states (https://www.iso.org/about/members accessed 2025-06-24T14:24:04+02:00) vs. 193 member states of the United Nations (https://www.un.org/en/about-us/member-states accessed 2025-06-24T14:25:08+02:00)

However, this standardization model is also characterized by long development cycles – typically measured in years – and a uniform approach to format and documentation.
Since the advent of the information and communication technology (ICT) and information technology (IT) sectors, which operate under much faster innovation cycles, standardization in these domains has increasingly moved away from standards bodies and toward open-source communities (Böhm and Eisape 2021).

Today, there is strong evidence that open-source constitutes the dominant development model in the software domain. The market shares of open-source software (OSS) are typically estimated between 70 % and 90 % (Musseau et al. 2022; Black Duck n.d.), and with indications of exponential growth extending back more than three decades (Deshpande and Riehle 2008).[2]

These communities operate on implementation-first principles: technical solutions are immediately applied, iteratively improved, and openly shared. Here, standardization occurs not by consensus ahead of implementation but as an emergent property of real-world use, remixing, and adoption. This principle has been referred to a meritocratic process in which actors continuously iterate on existing designs to produce "best-of-breed" solutions for their own use cases: The value of a solution is judged primarily by its feasibility and effectiveness and influence is earned through contribution and technical merit (Böhm and Eisape 2021).
Within this model, there is a strong incentive to integrate design changes as close to their original source as possible: In the common analogy of a river, feedback, bug fixes, or feature requests originating from downstream users – i.e. implementers of a solution – travel upstream to the community of the respective component (Whitehurst 2015).

As a result of the emergence of decentralized inclusive decision-making through open-source communities, standards bodies are becoming increasingly redundant in these sectors (Böhm and Eisape 2021). However, because open-source ecosystems typically focus on solutions close to or at the product level, they do not inherently compete with formal standards bodies. Rather, they offer a complementary approach to technical standardization. Several successful collaboration schemes between standards bodies and open-source projects exist, while greater policy alignment would further enhance these efforts (Blind, Thumm, and Böhm 2019).

In part, these open-source ecosystems are supported and moderated by dedicated standard-setting organizations (SSOs) offering a variety of (mostly) consortium-based processes. These SSOs adopt organizational structures similar to standards bodies but do not require representative consensus, which also allows them to move more quickly and adaptively. However, this may come at the expense of a broad underrepresentation of essential stakeholder groups – for instance, users in the case of IT and ICT standardization (De Vries, Verheul, and Willemse 2003).
Stakeholders are free to choose the SSO whose policies best reflect their interests and circumstances,

[2] Github.com, a large platform for open-source software development, stated in its Octoverse Report that 2024 the overall project base grew by 98%, suggesting that the exponential trend still continues; https://github.blog/news-insights/octoverse/octoverse-2024/ accessed 2025-09-10T18:51:16+02:00.

a practice sometimes referred to as "forum shopping" (Lerner and Tirole 2006).

The power-balance within these open-source ecosystems – and so also the possibility to govern parts of it with industry consortia – mainly relies on two key factors (Böhm and Eisape 2021):

1. The freedoms granted by open-source licenses, which give anyone the right to distribute modifications and remixes (forks);
2. a low cost of change, which enables as many communities as possible to put these forks into circulation, as software can be copied, modified, and distributed globally, almost instantly, and at negligible costs.

In contrast, for high-cost-of-change technologies – such as most hardware – these open-source meritocratic mechanisms are unlikely to generate equivalent standardization effects within the limited timeframe of a typical product life cycle (Böhm and Eisape 2021; Blind, Thumm, and Böhm 2019). Furthermore, consortium-based standardization in such fields is potentially problematic, as the high barriers for retroactive adjustments make these efforts more susceptible to dominance by individual actors (Lerner and Tirole 2006) – such as those observed, for example, at the Internet Engineering Task Force (Simcoe 2012).
Consequently, de jure standardization remains the default method for ensuring representation and broad legitimacy in high-cost-of-change sectors (Böhm and Eisape 2021).

Open-source hardware (OSH) occupies an intermediate position between the domains of open-source software and proprietary hardware.
Similar to software, OSH development is primarily community-driven, taking place in online environments that enable large-scale collaboration under the absence of restrictive intellectual property (IP) policies (Moritz, Redlich, and Wulfsberg 2018). OSH also bears the potential to achieve faster and more cost-efficient development cycles compared to proprietary hardware, partly due to network effects and strong participatory elements (Heikkinen et al. 2020). The effects of a low barrier to entry can be seen in OSS development practices, where early-stage involvement of users often results in feedback cycles that are "an order of magnitude faster than most commercial software projects" (Weber 2005).[3] However, these effects remain considerably more limited in the case of hardware.

As with software, the timelines of de jure standardization processes are misaligned with the pace of OSH development. Furthermore, the intentionally abstract nature of such standards precludes complex product-level specifications ("DIN 820 Beiblatt 3:2016-10" n.d., 5.1), while the established workflows and IP regimes of standards bodies typically do not align with open-source principles (Blind, Thumm, and Böhm 2019).

At the same time, practices from the OSS domain cannot be directly transferred to OSH due to the structural misalignments outlined above, compounded by the fact that OSH remains primarily driven by volunteer- or research-led communities, with industry participation and market capitalization

[3] Even though Weber's study is over twenty years old, the underlying dynamics have likely remained similar.

still significantly lower than in the OSS domain (Moritz et al. 2016).
Furthermore, just as definitions of open standards vary widely (Díaz-Marta and Ferrandis 2020; Krechmer 2006), so too do the procedural rules for standardization within OSS communities. Consequently, it remains unclear *which* procedures of open standardization would be well-suited for the context of OSH.

Although standardization practices within the OSH community do exist – e.g. concerning technical documentation and metadata (Bonvoisin et al. 2020) as well as, to a limited extent, on the product level[4] – these efforts remain isolated. Collaborations with standards bodies (Bonvoisin et al. 2020) and with SSOs, such as CERN White Rabbit with the Institute of Electrical and Electronics Engineers (IEEE) (Gamalielsson et al. 2022) or RISC-V with the Linux Foundation[5], provide further examples.
However, there are as yet no dedicated SSOs or standardization methods specifically tailored to the needs of OSH communities. Moreover, no systematic research has been conducted on the specific requirements for such methods.

This work aims to contribute to closing this gap without superseding existing infrastructures:
The objective is to develop an understanding of the needs of OSH communities in order to enable their effective initiation and management of, as well as participation in standardization projects, while at the same time complementing existing schemes and fostering collaboration with established institutions and actors – principally standards bodies and SSOs from the software domain.

A particular focus is placed on standards for the technical documentation of OSH, as the documentation constitutes the "source" of open-source hardware ("DIN SPEC 3105-1:2020-07" n.d., 3.8).
At present, the specific requirements for OSH documentation remain underdeveloped (Saubke, Krenz, and Redlich 2025). DIN SPEC 3105-1 provides only a minimal framework and delegates the definition of domain-specific requirements to external documents, referred to as Technology-specific Documentation Criteria (TsDC) ("DIN SPEC 3105-1:2020-07" n.d., 5.1). However, the TsDC referenced in the standard cover only a limited set of technological domains, remain relatively abstract, and have been developed from a narrow perspective, with contributions concentrated among just two principal authors over the past five years[6].
Beyond this, the field is partly shaped by best practices and conventions dispersed across the web, such as guidelines for optical breadboard assemblies[7] or conventions for bills of materials in electronic designs[8].

Standardized technical documentation holds several potential benefits for OSH:
It can enhance long-term replicability (Antoniou et al. 2021), especially post the prototyping stage

[4] For instance the Freespireco project in the domain of open-source ventilators; https://github.com/PubInv/freespireco accessed 2025-09-10T19:27:05+02:00.
[5] https://www.linuxfoundation.org/press/press-release/the-linux-foundation-and-risc-v-foundation-announce-joint-collaboration-to-enable-a-new-era-of-open-architecture accessed 2025-09-10T19:21:47+02:00
[6] https://gitlab.com/OSEGermany/oh-tsdc/-/graphs/master accessed 2025-09-11T13:10:08+02:00
[7] https://openscan-lsm.github.io/OpenScan-Hardware/ accessed 2025-09-11T13:13:34+02:00
[8] https://www.bunniestudios.com/blog/the-factory-floor-part-1-of-4the-quotation-or-how-to-make-a-bom/ accessed 2025-09-11T13:13:41+02:00

(Saubke, Krenz, and Redlich 2025), as well as facilitate design reuse, remixing, and the streamlining of contributions (Antoniou et al. 2021; Ezoji, Boujut, and Pinquié 2021).
Moreover, embedding de jure standards within TsDC – e.g., harmonized European standards or documentation of risk analyses – may improve the implementation of such standards in OSH designs. This, in turn, has the potential to simplify product liability management through the principle of "presumption of conformity" in product liability law (*Regulation (EC) No 765/2008* n.d. Article 11), thereby facilitating the commercialization of OSH products.

Compared to other areas of standardization within the OSH domain, particularly product-level standardization[9], documentation exhibits a relatively lower degree of complexity. While this may place some limits on the transferability of the findings, it is more suitable for the purposes of this research (i.a. testing) and provides a sound starting point for exploring the broader field of OSH standardization.

1.2 Goal

The objective of this work is to characterize and empirically test standardization methods tailored to the needs of open-source hardware (OSH) communities, while the focus lies on technical documentation.
These methods are compared with regard to their performance, with particular emphasis placed on two dimensions: the quality of the resulting standards and the process-related costs incurred during the standardization activities.
The analysis explicitly accounts for the heterogeneous and decentralized nature of OSH development, where standardization efforts are likely to be pursued in parallel by independent stakeholders and, in some cases, in modified forms.

The overarching goal of this research is not to derive generalizable findings, but rather to provide sufficient contextual insight to enable stakeholders within, or collaborating with, the OSH community to assess the transferability of the examined methods – e.g. community-driven standardization of open-source product specifications or the refinement of procedural rules for dedicated processes at standard-setting organizations (SSOs)[10].
Of particular interest is the identification of methods that yield satisfactory results when applied to documentation standards, striking a balance between the quality of the developed outputs and the resource commitments required for their realization – both from the perspective of participants and from that of the hosting parties.

[9] For instance the Freespireco project in the domain of open-source ventilators; https://github.com/PubInv/freespireco accessed 2025-09-10T19:27:05+02:00.

[10] For example, DIN provides an OpenSPEC process that explicitly targets open-source communities, but follows the same procedural rules as other DIN SPEC projects – except for the exploitation rights of the final document; https://din.one/spaces/viewspace.action?key=OpenSPEC accessed 2025-09-10T15:44:22+02:00.

1.3 Research Questions

The following four research questions (Q1 to Q4) have been formulated to develop standardization archetypes for the deployment in the OSH context:

1. **What eligible methods exist for the standardization of technical documentation in open-source hardware communities?**
   - What standardization practices exist in OSH communities?
   - What standardization practices exist in OSS communities and proprietary hardware environments?
   - What are essential characteristics determined by the procedural rules of the identified standardization methods?
2. **What factors determine the output quality and process costs of standardization methods in the OSH context?**
   - What characterizes standardization in the OSH context compared to other environments?
   - What are preconditions and key performance indicators for standardization methods to function successfully in the OSH context?
3. **What standardization archetypes can be deducted from the previous findings, under the condition to be deployable in a common framework?**
   - What are main differentiating characteristics among standardization methods identified in Q1? How can the methods be ported to the OSH context, considering the preconditions and KPIs from Q2? What archetypes can be deducted?
   - What are common scenarios of interaction – and potentially conflict – between these archetypes? How are these scenarios addressed by the procedural rules analyzed in Q1; how can they be addressed considering the factors identified in Q2?
4. **Within this framework, how do the archetypal models perform in the OSH context when applied to documentation standards?**
   - How can the KPIs be measured for the archetypes under realistic conditions?
   - What correlations can be observed between the KPIs?
   - What recommendations can be formulated for the further application of the archetypical models in the OSH context?

Chapter 2

Methodology

The methodology to answer the research questions is illustrated below in fig. 2.1.

The objective of **Q1**, **Q2** and **Q3** is to construct testable archetypal methods that can operate in a joint framework, with the aim of deploying them in the OSH context, particularly for the standardization of technical documentation.
The goal of **Q4** is a qualitative validation of the applicability of framework and archetypes in the OSH context, while also delivering insights on practical performance of the archetypes within the framework.

For **Q1**, a comprehensive literature review is conducted to identify established standardization methods in the OSH context; as well as in the OSS community and in a proprietary hardware context, as relatable domains with a significantly stronger record in standardization. The methodology for the literature review follows practices recommended by (Randolph n.d.), (Tranfield, Denyer, and Smart 2003) and (Webster and Watson 2002) and is detailed in Annex A.

In the OSH context, no relevant structure of SSOs exists today, much in contrast to the variety of SSOs in the OSS community or the network of national and international standards bodies in de jure standardization.
To make the different standardization methods comparable, they are reduced to their procedural rules, removing distorting aspects potentially emerging from e.g. scale effects or public mandates. The procedural rules needed for the analysis and comparison, are either explicitly formulated in dedicated documents, standards, contribution guides etc., or implied by the same. Consequently, the analysis and comparison is based on primary sources. The same applies for the relations to bordering and competing standards, determining the nature of the framework the different standardization practices operate in.

For **Q2**, a comprehensive literature review is conducted to identify preconditions for standardization methods to function successfully in the OSH context as well as key indicators for their practical performance (KPIs).

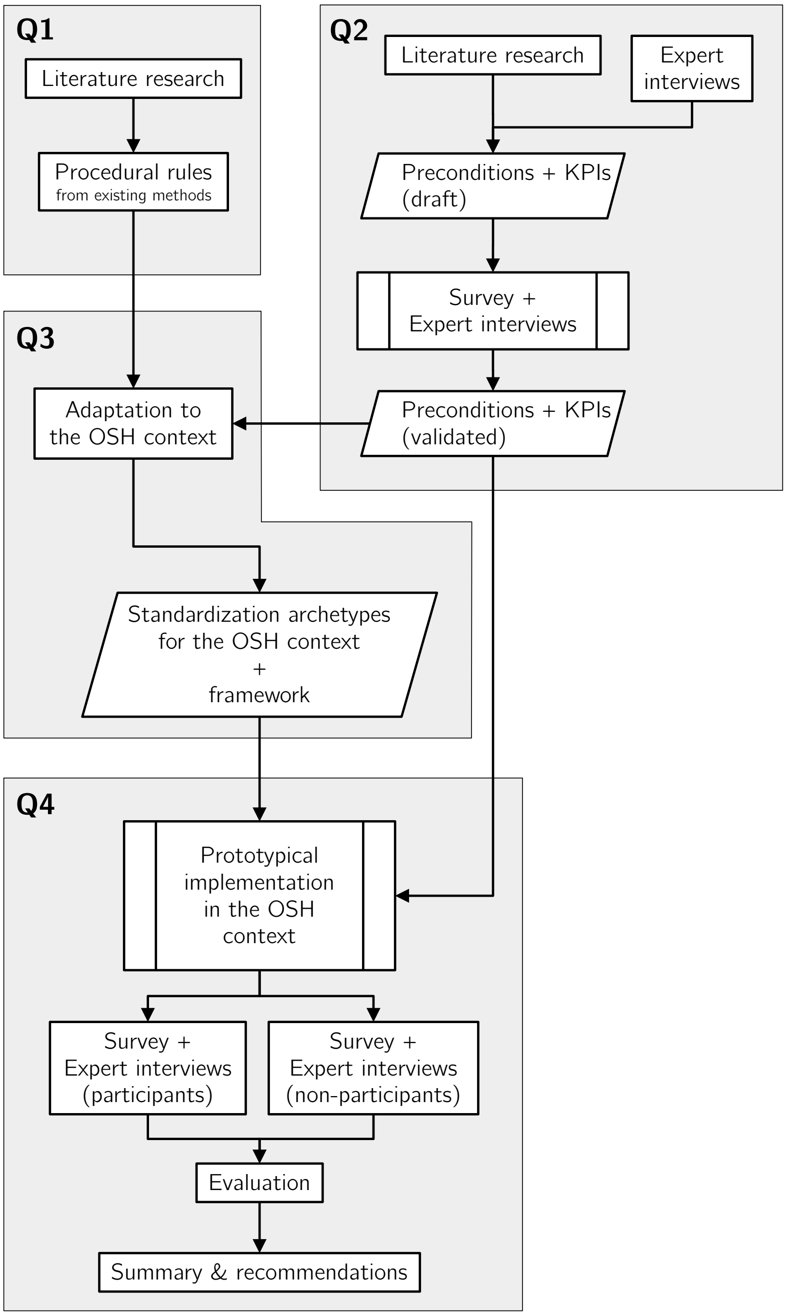

Figure 2.1: Schematic overview of the methodology.

As for **Q1**, methodology and results of the literature are detailed in Annex A.

An interim draft for preconditions and KPIs is deducted based on the findings of the literature review. KPIs are classified according to their association with either a) the quality of the developed standards or b) the process-related costs incurred during standardization.

Potential remaining open questions are clarified in interviews with manually selected domain experts.

To ensure applicability, the final draft is validated within the stakeholder groups defined for representative standardization ("DIN 820 Beiblatt 3:2016-10" n.d.), ported to the scope of standards for the technical documentation of open-source hardware. An overview alongside with examples is shown in table 2.1.

Table 2.1: Stakeholder categories as defined in the ISO Global Directory[2] alongside examples within the defined scope.

Category	Title (ISO)	Examples for actors within the defined scope
A	Industry and commerce	commercial actors producing, developing and distributing OSH or offering products and services built on top of OSH products or documentation
B	Government	regulatory institutions interacting with OSH communities or the concept as such (e.g. through funding, procurement policies, deployment, cooperation or commissioned development)
C	Consumers	bodies or individual experts independently representing an end consumer perspective; past, current or potential users of OSH products or documentation
D	Labor	unions and organizations representing the interests of employees developing, reviewing or using technical documentation of OSH
E	Academic and research bodies	research and educational facilities using, developing or researching OSH
F	Standards application	bodies for certification, conformity assessment bodies or review for technical documentation of OSH
G	Non-governmental organization (NGO)	voluntary maintainers of and contributors to OSH projects; non-profit organizations in the OSH context; other non-profit organizations operating for social or environmental concerns

[1] https://helpdesk-docs.iso.org/article/331-gd-stakeholders-categories accessed 2025-09-04T12:20:01+02:00
[2] https://helpdesk-docs.iso.org/article/331-gd-stakeholders-categories accessed 2025-09-04T12:20:01+02:00

The goal of the validation process is to ensure that the perspectives of all stakeholders relevant to standardization are adequately represented.
However, as OSH is a global phenomenon that enables adoption, participation, and interaction almost anywhere, and given the lack of systematic research on these specific stakeholder groups in the OSH context, the total population size of most categories cannot be reliably determined within the scope of this work. Exceptions to this are stakeholder categories E and F, which operate in a public and traceable manner and can be identified through openly accessible databases.
Accordingly, a qualitative design is adopted, the primary aim of which is not generalizability but the extraction of sufficiently rich expert knowledge to validate the findings and to enable the assessment of their transferability to other contexts.

For this purpose, non-probability sampling methods, as suggested in certain fields such as pharmaceutical research, are not feasible here (Draugalis and Plaza 2009; Lee and Landers 2022). To gain domain-specific insights, the population of stakeholders is first stratified according to the ISO stakeholder categories. Within each stratum, theoretical sampling is applied, targeting individuals whose expertise is expected to yield highly relevant insights. Sampling continues until theoretical saturation is reached – that is, when additional responses are unlikely to contribute substantially new information (W Lawrence 2014; Mayring and Fenzl 2019, 7.6).

To gain domain-specific insights, the population of stakeholders is first stratified according to the ISO stakeholder categories, as mentioned above. Within each stratum, theoretical sampling is pursued until a point of theoretical saturation is reached, i.e. a stage at which further expansion of the sample is unlikely to yield additional, substantively novel insights (W Lawrence 2014; Mayring and Fenzl 2019, 7.6).

To operationalize this approach, an iterative Hybrid Probabilistic-Snowball Sampling Design (HPSSD) is employed (Cantone and Tomaselli 2022).
Snowball sampling is particularly well-suited to research contexts in which expert knowledge is both scarce and difficult to access (Mayring and Fenzl 2019, 21.3.2). Beyond facilitating entry into otherwise hidden communities, it also enables the mapping of knowledge networks and the identification of central nodes within them (Lee and Landers 2022; W Lawrence 2014) – which facilitates the identification of relevant experts.
Moreover, because participants are nominated by peers rather than contacted via unsolicited approaches, higher response rates can be expected, which in turn reduces the likelihood of bias stemming from nonresponse. The inherent biases associated with snowball sampling are mitigated in this design through the probabilistic element, namely the random selection of subsets from sufficiently large initial samples (Cantone and Tomaselli 2022).

Initial sampling frames are constructed according to a principle of “growing theoretical interest” (W Lawrence 2014), thereby ensuring that the selection process maximizes relevance – and reduces the risk of prematurely terminating data collection due to the accumulation of confirmatory evidence suggesting an apparent (but misleading) point of saturation.

No additional restrictions (e.g. geographical scope, demographic markers) are imposed on the constitution of these initial frames.

The evaluation of survey data and expert interviews proceeds by means of a qualitative content analysis in accordance with Mayring (Mayring 1994). Where survey responses include statements of particular importance that remain ambiguous, or where substantial objections are raised, these are subsequently clarified through semi-structured expert interviews in accordance with Mayring (Mayring and Fenzl 2019, 44.3).

The HPSSD is repeated for each initial sample within each stakeholder category until the criterion of theoretical saturation is met across the entire set. Should the analysis reveal the necessity of significant revisions to the draft under consideration, the validation process is reiterated in full, using the revised version as its new basis.

The surveys further serve to identify standardization needs (TsDC) relevant to the prototypical implementations for **Q3** and to invite participants either to engage in the subsequent implementation of the proposed standardization methods – or to join a control group tasked with evaluating the resulting outcomes.

The iterative HPSSD is illustrated in fig. 2.2 below.

For **Q3**, the aim is to derive archetypes of standardization, together with a unifying framework that enables their joint deployment. This deduction builds directly upon the findings of **Q1**, while incorporating the validated preconditions and KPIs established in **Q2**.
Existing methods identified outside the OSH context are first transferred into the analytical frame and subsequently compared with the remaining methods by means of a morphological box.
This process yields the defining characteristics of viable standardization approaches suitable for application within the OSH domain, with particular emphasis on documentation standards.

On this basis, a framework is developed that draws on the procedural rules of the standardization methods identified in **Q1**. The framework functions as a shared foundation for the archetypes, ensuring their parallel and cooperative applicability within the OSH context.
Concluding this step, procedural rules are formulated for each archetype individually, while the overarching framework is embedded consistently across all of these rule sets.

For **Q4**, the developed framework is applied in four prototypical implementations, each of which encompasses all previously formulated archetypes. These implementations are designed as case studies, conducted under conditions that aim to approximate a realistic scenario as closely as possible.

In order to ensure comparability across the case studies, the scope of each standardization project is set to previously defined Technology-specific Documentation Criteria (TsDC) ("DIN SPEC 3105-1:2020-07" n.d.). During the survey in **Q2**, participants are asked to identify up to five TsDC they considered most important for standardization. Based on this input, TsDC scopes are

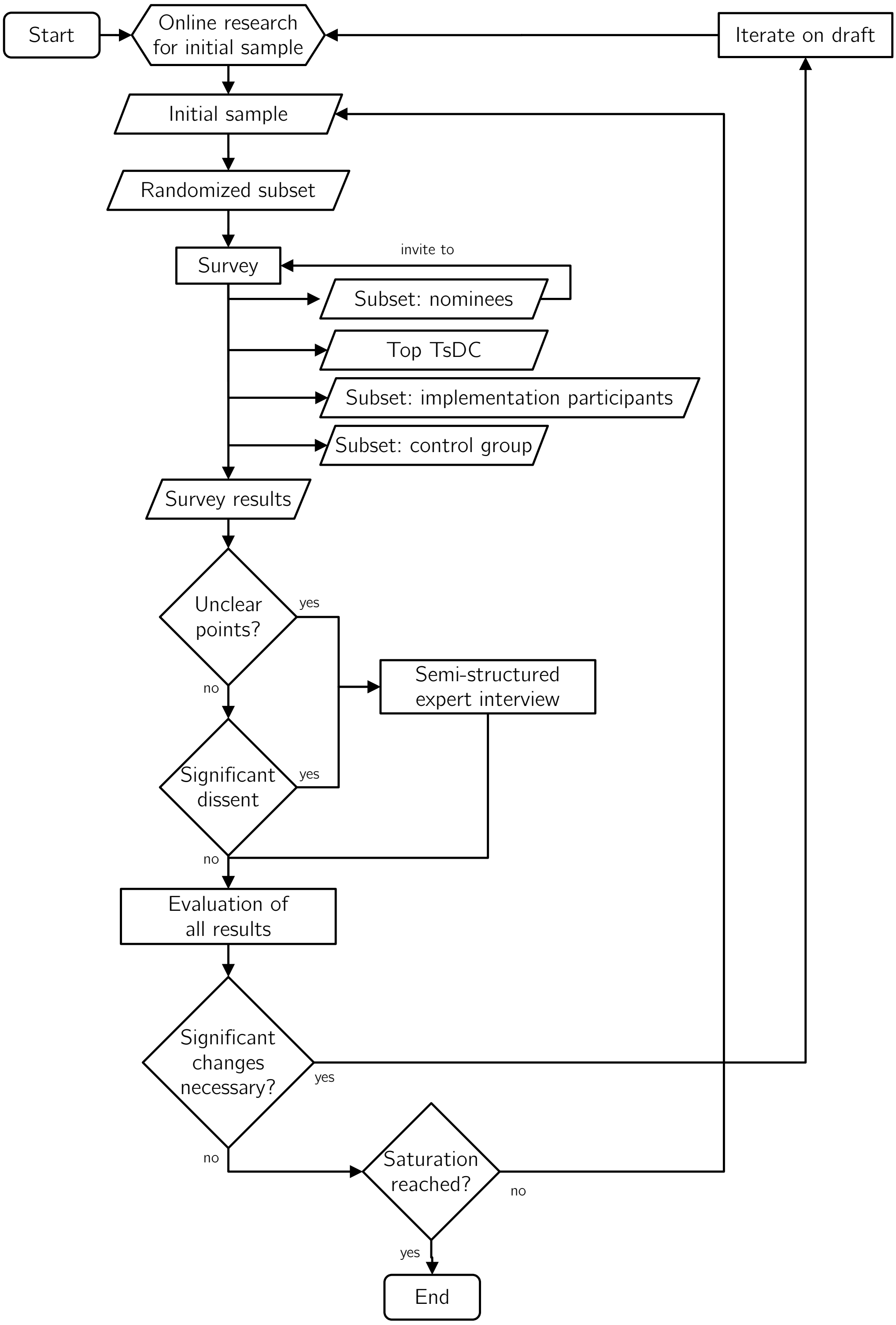

Figure 2.2: Flowchart for the iterative snowball sampling.

formulated and subsequently subjected to a prioritization poll among survey participants. The four highest-ranked TsDC thereby determine the thematic scope of the prototypical implementations.

All four implementations are carried out in parallel. Where necessary – as defined by the procedural rules or inherent to the developed framework – processes are moderated by the author of this work (e.g., managing invitations, hosting kickoff and onboarding calls).
The framework itself specifies the initial and final stages of an implementation and suggests a reasonable sequencing of the archetypes.

Upon completion of each implementation, both the output documents generated by the archetypes and the processes leading to them are evaluated against the KPIs established in **Q2**.
For this purpose, all participants are invited to take part in a survey assessing the quality of the outputs (acknowledging the potential bias inherent in their involvement in the process) as well as the associated process costs (drawing on their first-hand experience).
In addition, participants are asked to revisit the KPIs from **Q2** in order to identify whether their perceptions have shifted as a result of having actively participated in the implementations. As in **Q2**, semi-structured expert interviews are conducted in cases where survey responses raise significant questions or contain important but ambiguous statements requiring clarification.

Furthermore, members of the control group (formed through the survey in **Q2**) are invited to participate in a parallel survey, providing an external assessment of the output quality and expected process costs. Semi-structured expert interviews are likewise applied in this context when necessary.

All results are evaluated using the same qualitative content analysis method as in **Q2**, complemented by observations from the moderating perspective during the course of the implementations.
On the basis of these findings, recommendations are derived for future standardization efforts within or in collaboration with the OSH community.

Following, an example for an implementation is presented, based on an initial literature review:

Example Implementation:

Table 2.2 shows examples for four standardization archetypes.

Table 2.2: Examples for standardization archetypes based on initial literature review.

Archetype	Appearance	Governance
OSH Project	implicit open standard: de facto standard evolves from the effective documentation practice of OSH projects, no explicit standardization claim	governance-agnostic, no predetermined procedural rules (other than exploitation rights)

Archetype	Appearance	Governance
Specification Repository	explicit, informal open standard: dedicated open-source project to standardize documentation in dedicated upstream repositories	governance-agnostic, no predetermined procedural rules (other than exploitation rights)
Non-Representative Consortium	formal open standard	due process (e.g. JDF traditional/repository), not representative
Representative Consortium	formal open standard	due process (e.g. JDF traditional/repository + DIN 820), representative

The framework within which the archetypes operate mirrors the development environment of open-source hardware, with a particular emphasis on effective design reuse. Within this framework, a standard is developed as an open-source project, while the archetypes are primarily distinguished by their respective governance models, particularly regarding the degree of representativeness they enable.

As a unifying foundation, each project adheres to several common principles:

1. From a governance perspective, every project exists independently of other projects.
2. Representation is organized either through individuals or organizations, depending on the specific archetype.
3. All projects operate in a fully public and exclusively online manner,
4. while all relevant information is accessible under permissive open-source licenses.
5. Contributions may be submitted at any point in time,
6. and participants may join or leave without restrictions.
7. Moreover, projects can be duplicated and pursued as parallel initiatives (forks) at any stage of their development (as consequence of 4 and 6).

An implementation is structured as shown in fig. 2.3.

OSH projects that both 1) declare compliance with the requirements of DIN SPEC 3105-1[3], and 2) fall within the scope of the Technology-specific Documentation Criteria (TsDC) selected for the prototypical implementation are first identified through targeted online research.
These projects constitute the initial layer of standardization efforts within the framework and are formally invited[4] to participate in the standardization of the respective TsDC. In addition, invitations are extended to former survey participants who had expressed their willingness to engage in the implementation.

[3]This includes projects that have been certified by an alternative scheme such as the OSHWA Certification, https://application.oshwa.org/ 2025-09-10T13:19:54+02:00.

[4]Invitations are sent out openly, according to the communication channels provided by each project.

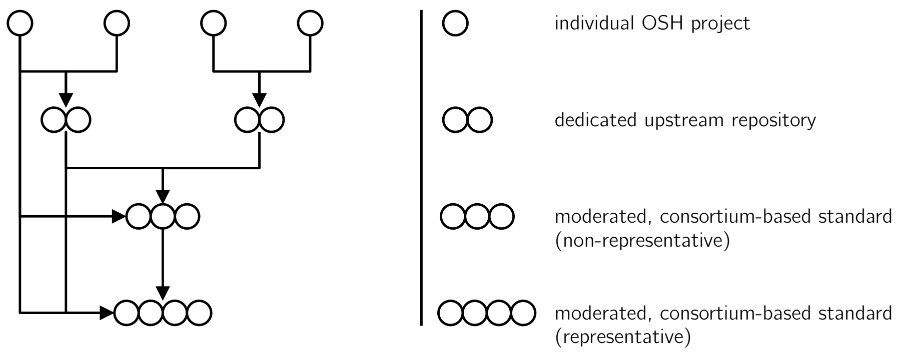

Figure 2.3: Schematic overview of an exemplary prototypical implementation of the framework.

The prototypical implementation and its objectives are introduced to all participants during a joint kickoff call, after which participants may decide to contribute to specification repositories either individually or within voluntarily formed groups – or alternatively, to join the process at a later stage.
Participants are allowed to invite further contributors at any time during the entire implementation – with the exception of individuals assigned to the control group.

Once two-thirds of all specification repositories have formally declared their conclusion, a critical mass is deemed to have been reached, and the process advances to the next stage.
At this juncture, all participants are invited to join a consortium-based standardization project with the aim of consolidating the outputs of the specification repositories. Participants are explicitly encouraged to involve additional contributors (e.g. expected downstream users of the standard) in order to broaden the relevance and applicability of the results. The consortium is moderated by the author of this work, following the procedural rules of the respective archetype[5].

Following the conclusion of the consortium stage, participants are invited to form a new consortium that is set up and operates in accordance with the provisions of DIN 820. This step includes the publication of an open call for participation on relevant community communication platforms, as well as the targeted invitation of underrepresented stakeholder groups to achieve a balance reflective of representativeness in line with ISO requirements (see table 2.1 above).

The declaration of conclusion by this representative consortium marks the formal endpoint of the prototypical implementation.

[5]Since, until this point, forking is still a valid option for conflict resolution, this step might involve the parallel moderation of multiple consortia within the same implementation.

Chapter 3

Limitations

The methodology applied in this work is not designed to yield generalizable results, neither for the OSH community as a whole nor for all conceivable applications of the proposed standardization methods.
The transferability of the findings is particularly constrained by two factors:
first, the relatively lower complexity of documentation standards compared to other potential standardization objectives[1];
and second, the absence of large community-based organizations within the processes, which might otherwise, for instance, be able to mobilize a broader pool of relevant experts to participate.
As a result, it remains difficult to determine whether and how the examined processes would perform in practice compared to already established approaches, such as de jure standardization or consortium-based standardization by SSOs in the OSS domain.

Furthermore, the qualitative validation of the standardization methods within the prototypical implementation is inherently limited to the processes actually employed by the participants. Affected procedural elements may include formal appeal mechanisms or iterative revision cycles, particularly after the final stage of an implementation.

[1] In particular, the practical influence of IP policies concerning standard-essential patents cannot be covered sufficiently, as it is arguably a very unlikely concern in the realm of technical documentation.

Chapter 4

Schedule

The work will start at the earliest possible point and is scheduled to be done by the end of December 2027.

The following milestones are planned in accordance with the research questions formulated in ch. 1.3:

- 26/Q1: literature review & expert interviews completed (research question 1, 2)
- 26/Q2: qualitative validation of KPIs and preconditions completed (research question 2)
- 26/Q3: standardization archetypes and framework developed (research question 3), prototypical implementations started (research question 4)
- 27/Q2: prototypical implementations completed (research question 4)
- 27/Q3: evaluation concluded (research question 4)
- 27/Q4: thesis ready for submission

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Annex

Contents

1 Annex A: Literature Review

1.1 Methodology

An initial literature review has been conducted to contextualize literature, identify valuable sources and to build the key terminology. The following journal databases as well as selected specific journals are searched for the key terminology:

- Comprehensive databases:
  - ScienceDirect, as it includes journals focusing on relevant areas for open standards, such as Computer Standards & Interfaces and HardwareX;
  - Oxford Academic, to cover IP-related literature, e.g. from the Journal of Intellectual Property Law & Practice;
  - BASE and CORE for relevant dissertations;
  - ISO Research Library for its explicit focus on standardization.
- Specific journals:
  - Journal of Open Hardware
  - Journal of Open Source Developments
  - Journal of Standardization
  - Journal of ICT Standardization
  - standards
  - International Journal of Standardization Research
  - Journal of Research of NIST
  - IEEE Xplore

The literature review is conducted under the following rules:

- The search process is documented in a log document.
- Boolean operators and regular expressions are used to specify search keys and to include associated terms (e.g. results for "standard" and "standardization" are both included when using the expression `standard*`).
  - Plurals are recognized by modern search algorithms and hence do not need to be considered as synonyms at the selected databases.
  - In case regular expressions are not supported (as e.g. at ScienceDirect), the search prompt is altered manually with selected synonyms.
- Results are limited to:
  - English- and German-written sources only;
  - the first 250 results per search.
- If a database or journal includes less then 100 publications, no search is conducted; instead, all publications are reviewed.
- Results are pre-filtered assessing the titles and abstracts of publications for relevance.
- Duplicates are merged *after* all searches (incl. pre-filtering) have been performed in all noted sources.
- The pre-filtered results are sorted by topic (based on their content), year of publication and type of affiliation of authors (e.g. research institute, industry, standard-setting organization).
- For each topic, the findings are formulated, whereas all data sources are reflected regarding their topicality and the transferability of their findings.

- Further actions are taken based on the identify gaps:
  - Semantic Scholar is used to review the citations of articles and books (backward search), and, conversely, articles and books citing key publications (forward search).
  - Complementary searches with new search keys.
  - Remaining gaps and ambiguities are addressed in expert interviews.

The following search keys have been defined:

- standardization practices in OSH:
  - `(standard* OR specification OR norm) AND open AND hardware`
- standardization practices in OSS:
  - `(standard* OR specification OR norm) AND open AND (source OR software)`
- standardization practices in proprietary hardware
  - `(standard* OR specification OR norm) AND ((de facto) OR consorti* OR (de jure)) AND (hardware OR machine OR device OR equipment)`
- OSH characteristics:
  - `(definition OR typology OR characteri* OR requirement OR aspect) AND open AND (hardware OR machine OR device OR equipment)`
  - `(analy* OR characteri* OR aspect OR requirement) AND open AND (hardware OR machine OR device OR equipment) AND (community OR development)`
  - `open AND (ip OR (intellectual AND property)) AND (hardware OR machine OR device OR equipment)`
- preconditions and KPIs:
  - `(definition OR typology OR characteri* OR requirement OR aspect) AND (open AND (standard* OR specification OR norm))`
  - `(issue OR concern OR problem OR complicat* OR dilemma OR dispute OR obstacle) AND (open AND (standard* OR specification OR norm))`
  - `(issue OR concern OR problem OR complicat* OR dilemma OR dispute OR obstacle) AND (standard* OR specification OR norm)`