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Howling for a New Standard - Deficits in Open Source Hardware Documentation

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Abstract

The sustainable reorganization of value creation structures starts rethinking the whole process, from the initial idea to the end of the product's life. Open Source Hardware (OSH) offers an approach in which a focal company is no longer the driver of product creation. With the increasing availability and growing number of OSH, a first attempt at standardization was made with DIN SPEC 3105. This research conducts an analysis of existing OSH to identify deficiencies in the Technical Documentation (TD) that impede its reproduction within professionally organized industrial environments, such as in small and medium-sized manufacturing enterprises.

Keywords: Buisness Model; Open Source Hardware; Customer Integration; Open Design

1. Introduction

The sharing of concepts, ideas, and thoughts is a fundamental human trait, which in the field of historical sciences is marked by the advent of written records as the starting point for detailed historical analysis [1]. The development of economic theories and intellectual property protection have significantly contributed to innovation and industrialization, as exemplified by Edison's Menlo Park [2]. Simultaneously, technical documentation became more professionalized and was advanced through new technologies [3]. The desire to document and disseminate knowledge has evolved over the centuries [4]. and can be interpreted as the transformation towards a knowledge-based society [5]. The invention of the personal computer reinvigorated the significance of freely sharing information. Initially, computers were employed in research and development, such as for complex calculations that later led to the development of modern CAD systems [6]. Software became a central theme, and the free software movement initiated by STALLMAN laid the foundation for Open Source, a concept that quickly extended to hardware [7, 8]. Recent studies indicate that the development of Open Source Hardware (OSH) has accelerated in recent years [9], likely due to the digitalization of society and improved collaboration tools [10]. This environment fosters further digitization of product creation processes within open communities, enabling the development of increasingly complex products and fostering interdisciplinary innovation [11, 12]. Approaches such as GERSHENFELD's "World of Bits and Atoms" and DIEZ's FabCity model demonstrate how global information flows can be linked to localized production [13, 14]. The design science sector is responsible for understanding and integrating these concepts with established proven standards of documentation and product development.

2. Objective of Research

For value creation systems focusing on global exchange of data and local materialization at the place of need the concept of OSH provides a promising footing and is an often discussed key enabler for implementation. Currently, these value creation systems coexist and are predominantly driven by enthusiastic end-users, so-called 'makers', who act as value-creating stakeholders and reproduce OSH designs

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independently. For years, the term OSH has been the subject of ongoing debate. Numerous hardware designs are published without an accompanying license, often due to authors' lack of awareness, indifference, or disagreement with the obligations imposed by such licenses. Consequently, this work will refer to the concept simply as Open Hardware (OH) rather than OSH.

However, extending this approach to include the 'masses' would lead to a value creation system, which negates the proven principles of division of labor and the advantages of specialization and knowledge aggregation. Thus, the new target group to incorporate are users who lack the skills, motivation, or resources to participate directly. This could make OSH accessible to a broader audience and promote free reproduction. The integration of these 'masses' of economically functioning actors, such as manufacturing companies, could help to promote resilient and independent value creation systems. In leading industrial nations, there are often widespread networks of small and medium-sized enterprises (SMEs). Integrating these professional value-creators would necessitate adherence to certain documentation standards. This raises the question: *Which aspects in the Technical Documentation of OH are underconsidered for the integration of more professionally organized producing enterprises in the OH value Chain?* This study builds on a previously published metric for evaluating OH, comprising 18 Main Subjects, conceptualized to assess various aspects of Technical Documentation (TD) for their applicability in an industrially organized environment [15]. The following sections analyze the evaluation results of five experts who assessed 49 freely available designs.

3. Theoretical Background

This chapter introduces the central concepts of OH, the basics of TD and the requirements for its replication.

3.1. Openness in developing Hardware

According to the Open Source definition, the leading paradigm is open access to all relevant information (e.g., source code, TD) for everyone to freely use, modify, and further develop an artifact. The goal is to foster collective innovation, enhance transparency, and facilitate collaboration. To do so, various licensing models, which may also permit commercial use, have been introduced in the past decades

Open Source has already found widespread and successful application in the software domain. However, the concept is increasingly gaining supporters and participatory efforts in the hardware sector. The development of such designs adheres to the principles of the *Open Design Paradigm*, which aims for the open and free creation of new hardware or software solutions [16]. Popular licenses are the CERN Open Hardware License (CERN OHL) or Creative Commons (CC) license, both of which comply with standards set by the Open Source Hardware Association (OSHWA), which defined a well-accepted licensing framework. They regulate the use of OH and provide structured guidance for publication.

OH designs today are shared through various platforms, many of which also facilitate the individual's interaction with the global community. A recently published study identified and analysed nearly 50 platforms, which collectively offer millions of designs freely accessible to users [9].

3.2. Insights of Technical Documentation

TD encompasses all necessary information to successfully navigate the product lifecycle as defined by DIN ISO 15226 'Product Life Cycle' [17]. The product lifecycle includes all phases of a product, from inception to 'end of life'. Modern approaches, such as applying the R-Principles, aim to extend this cycle by optimizing product lifespan. The primary goal of technical documentation is to establish a foundation that facilitates efficient and effective development, utilization, maintenance, and other lifecycle-relevant activities.

Technical documentation relies on both international and national standards. Key standards include VDI 4500 (B1, B2, B3, B4, B6) 'Technical Documentation' [18], DIN EN ISO 10209 'Technical Product Documentation' [19], and DIN ISO 11442 'Technical Product Documentation – Document Management' [20]. These standards define specific requirements and terminology to regulate the purpose and creation of TD. Standardization ensures uniform quality, enabling proper use within organizations and across corporate boundaries. In the field of OH development, Germany has taken a pioneering step with DIN SPEC 3105 [21]. It offers generic recommendations on determining the necessary scope of TD for specific products, which should help developers address individualized requirements. Capturing the requirements of an open and collaborative development environment in a standard helps to bring these modern concepts closer to traditional approaches.

3.3. How to Replicate Open Hardware

Currently, OH is predominantly shared between users, often peer-to-peer. These artefacts are shared mainly on digital platforms, characterized by collaboration and exchange even in the early stages of development. The spectrum of OH designs ranges from simple everyday objects to highly specialized technologies such as sensors, medical technology or manufacturing systems.

A parallel approach in OH follows a more commercially oriented model: designs are made publicly available while the necessary components are sold as kits. This model offers customers cost and quality advantages and is employed by some of the most economically successful OH projects. On the other hand, high-tech initiatives, such as developing an Open Source MRI, are typically supported by institutional frameworks and the involvement of researchers and experts.

Regardless of the approach, OH emphasizes user participation. Many of the components used in OH are manufactured through industrial-scale production or SMEs and then integrated into larger systems. To make OH accessible to users who may not wish to engage directly in the value creation process, integrating local enterprises into the value chain presents a promising solution. With their specialized capabilities, they could efficiently and flexibly produce smaller quantities tailored to local markets [21].

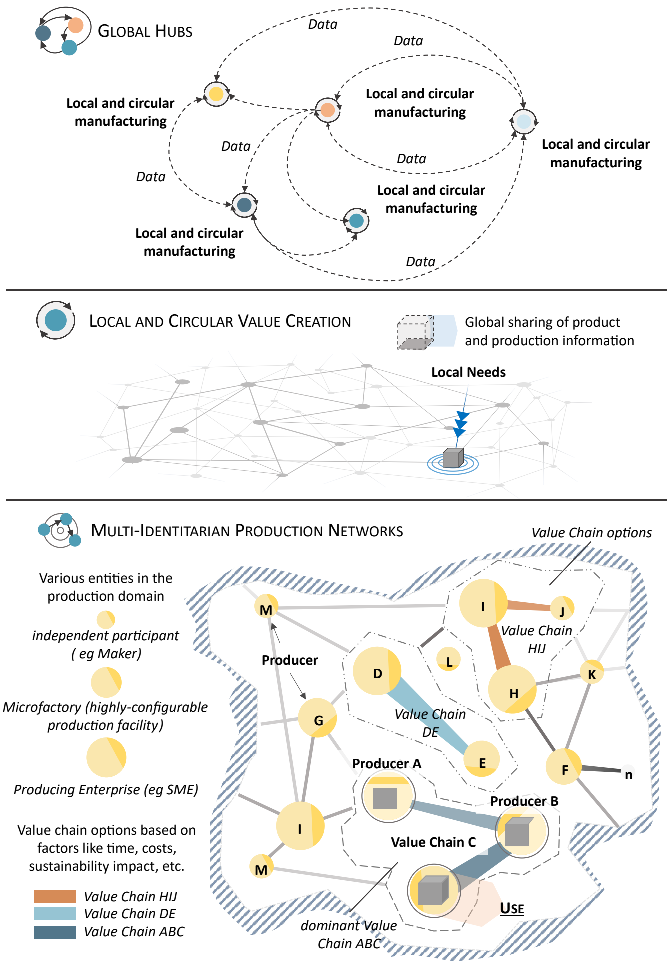

Fig. 1. Opportunities to replicate OH in Multi-Identitarian Networks.

These enterprises could pool their expertise to tackle more complex value creation tasks when connected in networks. Figure 1 illustrates potential value chains designed to address such challenges. The intelligent design of these networks is a focus of ongoing research. It is conceivable that various stakeholder groups, including users, enterprises, and institutions, could collaborate on value creation tasks. Production within so-called multi-identitarian networks combines different types of entities, such as maker spaces, mini- and micro-factories, reconfigurable manufacturing units and SMEs. These networks could bundle diverse production capacities, aiming to solve complex value-creation tasks. This concept represents an evolution of lately discussed hybrid production networks [22].

4. Rating of Open Hardware Technical Documentation

The following section outlines the derivation of the criteria, provides a detailed description of each, and introduces their application in evaluating the integration SMEs in OH value chains.

4.1. Introduction the Main Subjects of what…?

The criteria were tested on OH in a prior publication and evaluated for general applicability using statistical methods. The ratings from five experts were assessed for inter-rater reliability to ensure that the criteria can be universally applied to any OH design. The evaluation metric comprises 18 main subjects, derived by clustering commonly described objects of technical documentation in the literature. SAUBKE et al. detail this approach in a previously published study [15]. Table 1 provides an overview of the main subjects and their brief descriptions.

Table 1. List of Test Criteria.

NR	MAIN SUBJECT	DESCRIPTION
1	Ideation	▪ Inform. Accessibility Focus ▪ Context Documentation Importance
2	Marketing Aspects	▪ Marketing Data Included ▪ Advertising Concepts Provided
3	Product Description	▪ Product Overview Provided ▪ Comprehensive Understanding Supported
4	Standards and Norms	▪ Using Standards and Norms ▪ Interface Documentation Provided
5	Concept and Research	▪ Development Process Details ▪ Associated Work Referenced
6	Technical Details	▪ Testing Details Included ▪ Technical Description Provided
7	Models and Drawings	▪ Design Data Provided ▪ Processing Phases Included
8	Prototyping	▪ Prototype Realisation Documents ▪ Testing Scope Included
9	Manufacturing Related	▪ Production Information Documented ▪ Assembly Instructions Included
10	Installation	▪ Installation Details Provided ▪ Commissioning Documentation Included
11	Operations	▪ Operation Information Included ▪ Training Documents Provided
12	Transport and Logistics	▪ Transport Documentation Provided ▪ Logistics Information Included
13	Maintenance	▪ Maintenance Documents Provided ▪ Diagnostics Information Included
14	Safety Use	▪ Safety Instructions Included ▪ System Labelling Provided
15	Repair and Update	▪ Repair Information Provided ▪ Training Measures Included
16	Material and Composition	▪ Material Data Included ▪ Usage Instructions Provided
17	Disposal and Recycling	▪ Material Data Documented ▪ Usage Instructions Included
18	Monitoring and Improvement	▪ Market Monitoring Documents ▪ Feedback for Improvement

4.2. Explanation of the Likert Rating System

The expert evaluation was conducted through a systematic process using a five-point Likert scale. Each main category was represented by a specific element. A symmetrical evaluation system was employed, with equally weighted intervals to ensure consistent assessments. The scale follows a multi-level structure designed to measure agreement or alignment with the criteria. The evaluation was carried out according to the following scheme:

- ***1-point rating:*** *No TD Objects Addressed*
- ***2-point rating:*** *Primitive Object Consideration*
- ***3-point rating****: Basic Criteria Fulfilled*
- ***4-point rating:*** *Extensive Object Consideration*
- ***5-point rating:*** *Meets Industrial Standards*

The rating system enables experts to provide a precise and nuanced evaluation of the respective main subjects. The goal is to precisely classify the extent to which each cluster of technical documentation is addressed. A score of 1 indicates that the relevant area of technical documentation has been entirely neglected, while a score of 5 signifies that the documentation in this area meets industrial standards. Such a high rating implies that the corresponding OH design could be reproduced in an industrial production environment without significant modifications.

5. Discussion of the Rating Results

This section presents the evaluation results and systematically analyses the fundamental aspects of TD compliance, highlighting the varying levels of fulfilment and their significance

5.1. Understanding the Results

The results of the evaluation conducted by five experts are presented in Table 2. The experts, all from the field of production engineering, underwent intense training on the application of the 18 main subjects, including more detailed explanations of each factor and examples for rating. The 49 designs evaluated were randomly selected from various sources. During the evaluation, it was checked whether the designs were published under an OH license. It is a common approach that platforms host both licensed and unlicensed hardware designs. It appears that while many users are familiar with the concept of Open Source, the importance of including a license when publishing designs is often considered secondary. In Table 2, the averaged expert ratings for each of the 49 OH designs in the 18 different rating criteria (=main subjects) are presented. Additionally, the mean values for all artefacts, OH licensed and non-licensed across all designs, are recorded. A list containing the respective links to the designs is available upon request from the corresponding author.

The main subject *Ideation* received an average rating of just above 1, indicating that most designs lack documentation on the ideation process or justification for developing a new solution. Similarly, low ratings were observed for *Marketing Aspects*, *Concept and Research*, *Installation*, *Operations*, and *Maintenance*. The low consideration of *Marketing Aspects* is likely due to the current dissemination of OH, which is primarily characterized by direct user-to-user interactions, rendering marketing less significant. The use of a design by an interested other party is not incentivized; this can be used as an explanation. As expected, the main subject *Concept and Research* received the lowest ratings overall. This main subject considers that fundamental innovations or technological advances may occur during development in special cases that need to be documented accordingly. The advent of new materials or connection techniques typically requires a significant financial commitment. Therefore, they are currently mainly found in a corporate environment, especially since the legal protection and integration of OH license models into existing patent systems are the subject of current research. This illustrates that not all main subjects are to be regarded as mandatory. Nevertheless, it is essential to identify and consider such aspects, especially in view of the fact that highly innovative machines and experimental apparatus from research and development at universities are increasingly being published under OH licenses. These innovations are often novel and promising but at the same time do not offer any distinct commercial exploitation potential. Therefore, cost-intensive patent applications are often avoided. Publication as OH offers an opportunity to share these developments and make them accessible to other scientists. Appropriate documentation is of central importance here. The unexpectedly low ratings for *Operations and Maintenance* are unclear. A plausible explanation could be, that many OH designs leave the developers' focus once the prototype is completed. Insights into maintenance, upkeep, and operational aspects often emerge during extended use. Adding this information retrospectively could be perceived as a burden. In summary, the evaluation underscores deficiencies in research, maintenance, and operational documentation, highlighting areas for improvement to make OH designs more broadly applicable and effective. Unexpectedly, only a few designers address documentation according to recycling or general end-of-life management. Moreover, it is concerning that documentation ensuring the safe use of the products was only rarely identified. These deficits highlight critical areas for improvement to promote the dissemination and sustainable application of OH.

Looking at the main subjects with average higher ratings, the evaluation shows that they more relate to the development and modelling phase. Mapping the main subjects along the PLC highlights a clear pattern: while documentation quality and scope decline significantly after the prototyping phase or production stage, areas related to design and development are notably well-documented. High ratings were particularly observed for subjects such as *Technical Details, Product Description*, *Conceptualization*, *Models and Drawings* and *Material Information*.

These findings align with the principles of the OH movement, which prioritizes OHs creative and experimental use by individual makers. Production by third parties appears to play a less central role. The analysed documentation and fragments of TD confirm that participating makers primarily create designs for personal use, without explicitly considering subsequent reproduction, commercialization, or market introduction. This reinforces the previously mentioned user-to-user approach. The results do, however, demonstrate a clear direction. Most OH designs can only be replicated with a great deal of rework or even a complete redesign in a professional context. But this is precisely where the costs become prohibitive, and are hardly bearable for the potential end user. A more structured approach to documentation and better specifications are essential.

5.2. Further Interpretation

The random selection of designs on publishing platforms of OH did not specifically account for the presence of an OH license, while the designs were sourced from platforms known for hosting multiple OH, licensing is not mandatory. The results were compared to reveal differences in TD between designs with an OSH license and those without.

Table 2. Rating results.

			Main-Subjects [*Mean value of the expert assessment*]																			
Number	Name		Average	Ideation [1]	Marketing Aspects [2]	Product Description [3]	Standards and Norms [4]	Concept and Research [5]	Technical Details [6]	Models and Drawings [7]	Prototyping [8]	Manufacturing Related [9]	Installation [10]	Operations [11]	Transport and Logistics [12]	Maintenance [13]	Safety Use [14]	Repair and Update [15]	Material and Composition [16]	Disposal and Recycling [17]	Monitoring and Improvement [18]	**Open Source Hardware Licence**
1	Alvarostool	**Ø**	*1,7*	1,0	1,0	2,0	1,2	1,0	1,0	4,0	1,2	4,0	1,0	1,0	3,0	1,4	1,0	1,0	2,2	1,2	2,8	yes
2	Angle grinder stand	**Ø**	*1,9*	1,0	1,2	3,0	1,0	1,0	2,6	5,0	1,0	4,0	1,0	1,0	3,0	1,0	1,0	1,0	5,0	1,0	1,0	
3	Axial Flow Turbine 25kW	**Ø**	*1,5*	1,0	1,2	1,4	2,6	1,0	3,0	4,8	1,0	1,0	1,2	1,0	1,0	1,0	1,0	1,2	1,0	1,0	1,0	
4	Barschrank	**Ø**	*1,3*	1,0	1,0	1,0	1,0	1,0	1,0	1,8	1,0	1,0	1,2	1,0	2,8	1,0	1,0	1,0	2,8	1,0	1,2	yes
5	Biertischgarnitur	**Ø**	*1,8*	1,0	1,0	1,4	1,0	1,0	1,2	4,0	2,2	5,0	1,0	1,0	2,8	2,0	1,0	1,0	4,0	1,0	1,0	
6	Bioamp Standard	**Ø**	*1,7*	1,2	1,0	1,8	2,6	1,0	1,8	4,0	1,0	2,8	1,0	1,0	1,8	1,0	1,0	1,2	4,0	1,0	1,2	
7	Bioampo EMG PILL	**Ø**	*1,8*	1,0	1,0	4,2	3,2	1,0	2,4	4,2	1,0	2,8	1,0	1,0	1,0	1,0	1,0	1,0	4,0	1,0	1,0	yes
8	Blower 4020	**Ø**	*1,3*	1,0	1,0	1,8	1,0	1,0	1,0	3,0	1,0	1,0	1,0	1,2	1,0	1,0	1,0	1,0	3,0	1,0	1,0	yes
9	Boo-X	**Ø**	*1,6*	1,2	1,0	1,8	1,0	1,0	1,0	1,8	2,4	2,0	1,0	1,0	2,8	1,0	1,2	1,2	3,2	1,0	2,8	yes
10	CNC Router	**Ø**	*1,6*	1,4	1,0	2,0	1,0	1,0	1,4	4,8	1,2	2,4	1,0	1,0	2,2	1,0	1,0	1,0	4,0	1,0	1,0	yes
11	College Loft Bed	**Ø**	*1,2*	1,0	1,0	1,8	1,4	1,0	1,0	1,6	2,0	1,8	1,0	1,0	1,2	1,0	1,0	1,0	1,0	1,0	1,0	yes
12	Dental Chair Lever (Hl020)	**Ø**	*2,4*	1,0	1,2	1,8	3,2	1,2	1,0	3,6	4,8	4,6	4,0	1,0	1,8	1,2	4,8	1,2	5,0	1,0	1,0	yes
13	Desert Eye: Military Surv.Robot	**Ø**	*1,3*	2,8	1,2	1,6	1,0	1,0	1,0	2,0	1,6	1,2	1,0	1,0	2,0	1,0	1,0	1,0	1,0	1,0	1,4	yes
14	Downsized End Table	**Ø**	*1,1*	1,4	1,0	2,0	1,0	1,2	1,8	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,2	yes
15	Drill Guide (DIY)	**Ø**	*1,2*	1,0	1,0	2,0	1,0	1,0	1,0	1,0	2,6	2,2	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	yes
16	Dyn. Robot for Embodied Testing	**Ø**	*1,6*	1,6	1,0	2,0	3,0	1,0	2,0	1,0	3,2	3,2	1,0	1,0	2,0	1,0	1,0	1,0	1,4	1,0	1,0	
17	Eight	**Ø**	*1,5*	1,2	1,0	1,8	1,0	1,0	1,0	3,0	1,8	1,8	1,0	1,0	3,0	1,0	1,0	1,0	1,8	1,0	2,6	yes
18	EMG Prosthetic Hand (3D Printed)	**Ø**	*1,5*	1,0	1,0	1,8	1,0	1,2	1,0	2,8	3,4	3,2	1,0	1,0	1,8	1,0	1,0	1,0	2,0	1,0	1,0	yes
19	Fingerprint Door Lock	**Ø**	*1,7*	1,2	1,2	3,0	1,2	1,0	1,2	3,0	3,0	3,8	1,0	1,0	1,0	1,0	1,2	1,0	3,2	1,0	1,0	
20	GasSensorIOT	**Ø**	*1,3*	1,0	1,0	2,0	1,0	1,2	1,0	4,0	1,0	1,8	1,0	1,0	1,0	1,2	1,0	1,0	2,0	1,0	1,0	
21	Hash Humanoid Robot V3	**Ø**	*1,5*	1,8	1,0	2,0	1,0	1,2	1,0	2,8	1,8	1,8	1,0	1,0	2,0	1,2	1,2	1,0	2,8	1,0	1,0	
22	Imaging Rig - Blood Analysis (Rms)	**Ø**	*2,2*	1,0	1,0	4,0	1,8	1,2	4,0	3,6	2,2	3,8	3,6	1,0	1,6	1,0	1,0	1,0	5,0	1,0	1,0	yes
23	Lily-Bot Version 2: OS Aca. Robot	**Ø**	*1,5*	2,6	1,0	2,0	1,0	1,0	1,0	2,2	1,8	1,8	1,0	1,0	1,8	1,2	1,2	1,0	3,0	1,0	1,0	yes
24	Neodymium Angle Encoder	**Ø**	*1,9*	1,2	1,0	1,8	1,0	1,0	4,0	4,0	3,8	3,0	1,0	1,0	1,2	1,0	1,0	1,0	4,0	1,0	1,4	yes
25	Original Prusa Mini	**Ø**	*2,0*	1,0	1,0	3,0	1,0	1,0	4,8	2,8	4,0	1,0	1,0	1,0	1,8	1,0	1,0	1,0	5,0	1,0	4,2	yes
26	Ötz-T: OS Turbidity Sensor	**Ø**	*1,3*	1,0	1,0	3,2	1,0	1,0	1,0	1,2	1,0	1,8	1,0	1,0	1,0	1,0	1,0	1,4	3,0	1,0	1,0	
27	Pliers (GN008)	**Ø**	*2,3*	1,0	1,0	3,2	1,0	1,0	2,8	4,8	4,0	4,4	1,2	1,0	3,0	1,2	1,0	1,0	5,0	1,0	3,0	
28	Poseidon: OS Bioinstrumentation	**Ø**	*1,7*	1,0	1,0	3,2	1,0	1,0	2,8	4,0	3,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	4,0	1,2	1,0	yes
29	Prusa I4 Plus	**Ø**	*1,6*	2,0	1,0	2,0	1,0	1,0	1,0	4,8	3,6	1,8	1,2	1,0	1,6	1,0	1,0	1,0	1,0	1,0	1,0	yes
30	Robotics Arm (DIY)	**Ø**	*1,4*	1,0	1,0	1,8	1,2	1,2	1,8	3,0	1,8	3,8	1,0	1,0	1,0	1,2	1,0	1,2	1,0	1,0	1,0	yes
31	Scalpel Truss Handle (HL004)	**Ø**	*2,4*	1,0	1,0	3,0	3,0	1,0	1,4	3,8	3,8	4,6	3,8	1,2	2,4	1,0	5,0	1,0	4,6	1,0	1,2	yes
32	Self-Contained Breathing Appa. Mask	**Ø**	*1,8*	3,0	1,0	1,8	2,4	1,0	3,6	1,0	2,0	3,0	1,2	1,0	1,0	1,0	1,0	1,2	5,0	1,0	1,0	yes
33	Spider Quadruped	**Ø**	*1,3*	1,2	1,0	2,0	1,0	1,0	1,0	2,8	1,0	1,0	1,0	1,2	2,0	1,0	1,0	1,0	2,0	1,2	1,0	
34	Stoote	**Ø**	*1,3*	1,0	1,2	1,8	1,0	1,0	1,4	2,0	1,0	1,0	1,0	1,0	1,0	1,2	1,0	1,0	2,0	1,2	2,8	yes
35	Stream	**Ø**	*1,6*	1,2	1,0	2,0	1,0	1,0	1,0	2,8	2,0	2,2	1,0	1,0	3,8	1,0	1,0	1,0	2,0	1,0	2,8	yes
36	Stuhl	**Ø**	*1,1*	1,0	1,0	3,0	1,0	1,0	1,0	1,0	1,0	1,0	1,4	1,0	1,0	1,0	1,0	1,0	1,2	1,0	1,0	yes
37	Thermoelectric Fan	**Ø**	*1,4*	1,0	1,0	1,8	1,0	1,2	1,0	1,0	3,0	2,0	1,2	1,0	1,2	1,0	1,0	1,0	3,0	1,0	1,0	yes
38	Thread 11mm (Wa014)	**Ø**	*2,4*	1,0	1,0	2,8	3,0	1,0	1,0	3,8	4,8	4,6	3,6	1,0	2,0	1,0	4,8	1,0	4,8	1,0	1,0	
39	Tizi	**Ø**	*1,5*	1,0	1,0	1,6	1,0	1,2	1,0	3,4	1,4	2,8	1,0	1,0	1,4	1,0	1,0	1,0	1,6	1,0	3,0	yes
40	Tryoh2	**Ø**	*1,3*	1,0	1,2	1,0	1,2	1,0	1,0	2,0	1,0	1,0	1,0	1,0	3,2	1,0	1,0	1,0	1,0	1,0	3,2	yes
41	Tweezers-Forceps (Hl011)	**Ø**	*2,3*	1,0	1,0	2,8	3,0	1,0	1,0	3,8	3,6	4,8	3,4	1,2	2,0	1,0	4,4	1,0	4,6	1,0	1,0	
42	Two Leg Robot	**Ø**	*1,8*	1,4	1,0	4,2	1,0	1,0	1,0	4,0	3,0	3,0	1,0	1,0	2,0	1,0	1,0	1,2	3,6	1,0	1,0	yes
43	Unique Shelving Unit	**Ø**	*1,3*	2,6	1,2	2,0	1,0	1,0	1,0	1,0	2,0	2,0	1,0	1,0	1,0	1,0	1,2	1,0	1,0	1,4	1,0	yes
44	V Stool	**Ø**	*1,5*	1,4	1,0	1,0	1,0	1,0	1,0	2,2	1,0	3,0	1,0	1,0	2,8	1,0	1,0	1,2	3,0	1,0	3,2	yes
45	Ventilator Connector (HL010)	**Ø**	*2,3*	1,0	1,2	2,0	2,6	1,0	1,0	3,8	4,8	4,6	3,4	1,0	2,0	1,0	4,6	1,0	4,6	1,0	1,0	
46	Vex Robotics Project Tej4m	**Ø**	*1,2*	1,0	1,0	2,2	1,0	1,0	1,0	1,0	2,0	1,8	1,0	1,0	1,4	1,0	1,0	1,0	1,8	1,0	1,0	
47	Weather Station Connector	**Ø**	*2,3*	1,0	1,0	2,2	2,6	1,0	1,0	4,6	5,0	4,6	1,0	1,2	1,8	1,0	4,8	1,0	5,0	1,0	1,0	
48	Wrist Brace (Small) (Hl013)	**Ø**	*2,3*	1,0	1,2	1,6	2,8	1,0	1,0	3,8	4,2	4,8	3,4	1,0	2,0	1,2	5,0	1,0	5,0	1,0	1,2	
49	Xray Machine (Homemade)	**Ø**	*1,3*	1,0	1,0	2,2	1,0	1,0	1,0	2,2	1,8	2,2	1,2	1,0	1,0	1,0	2,0	1,0	1,6	1,0	1,0	
	All -Overall - Mean	**Ø**		*1,25*	*1,04*	*2,19*	*1,49*	*1,04*	*1,53*	*2,93*	*2,30*	*2,63*	*1,41*	*1,02*	*1,80*	*1,06*	*1,58*	*1,04*	*2,93*	*1,02*	*1,45*	
	OH - Mean	**Ø**		*1,21*	*1,05*	*2,09*	*1,61*	*1,04*	*1,52*	*2,91*	*2,57*	*2,86*	*1,60*	*1,03*	*1,87*	*1,08*	*1,87*	*1,03*	*3,05*	*1,02*	*1,51*	
	Non OH - Mean	**Ø**		*1,33*	*1,02*	*2,39*	*1,26*	*1,02*	*1,55*	*2,96*	*1,80*	*2,19*	*1,05*	*1,01*	*1,67*	*1,04*	*1,04*	*1,06*	*2,72*	*1,04*	*1,34*	

In Figure 2 an inverted spiderweb-diagram is shown, with low values in the outer areas and highest values in the middle. Since the overall ratings are pretty low, the inversion helps to show the results in areas with higher resolution. Examining the curves reveals a highly consistent pattern, as they are nearly congruent. There are no significantly superior regions, indicating that the evaluation results are remarkably similar. Licensing does not verifiably improve the quality of TD. However, the number of designs examined is seriously reduced by splitting into two groups. Overall, far too few designs are examined; a larger study must be carried out here.

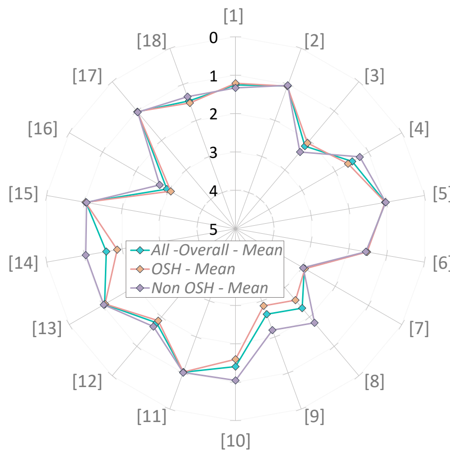

Fig. 2. Comparison of OSH and OH according to mean values.

6. Conclusion

The analysis reveals significant deficits across all areas of Technical Documentation (TD) in the evaluated Open Hardware (OH). The results underscore significant gaps in the alignment of documents with the Product Life Cycle (PLC), particularly beyond the materialisation phase (e.g. Prototyping). This suggests that the transfer of information through documentation often neglects post-prototyping aspects. A plausible explanation lies in the prevalent user-to-user sharing model, where users themselves handle replication, and having necessary qualifications. However, broadening the accessibility of Open Hardware (OH) to the 'masses', such as through the integration of professionally organized producers in the value chain, new strategies for Open Hardware (OH) development and documentation are needed. However, the limited number of designs assessed constrains the generalizability of the findings. Recalling the results of a earlier mentioned study on Open Hardware (OH) publishing platforms [9], which identified a substantial number of designs, published on various platforms highlights the need for a more comprehensive and systematic approach to future evaluations. Future research should focus on systematically expanding the dataset of designs while also introducing a more detailed differentiation between the platforms hosting the designs and the products themselves. Despite these, the criteria used in this study have proven to be robust and insightful, demonstrating their capability to assess the applicability of Technical Documentation (TD) effectively. Open Hardware (OH) still has significant potential to support sustainable and collaborative value creation.

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