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Title: Open Hardware Adoption: Insights from Community Voices and Strategies for Overcoming Complexities

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Open Hardware Adoption: Insights from Community Voices and Strategies for Overcoming Complexities

Seckin Celik, Erica Santini

Abstract

This study investigates the drivers of open hardware (OH) adoption using a qualitative approach to evaluate narratives from 28 community podcasts. Despite OH's transformative potential to democratise technological innovation through open access and collaborative development, scholarly understanding of its adoption remains fragmented. Drawing from Unified Theory of Acceptance and Use of Technology 2 (UTAUT2), this research analyses how community narratives illuminate both known and emerging determinants of OH adoption. Findings demonstrate that performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, price value, and habit, are still important drivers in the adoption choice. In particular, social influence through peer endorsement and facilitating conditions such as reliable infrastructure and accessible platforms emerged as critical adoption enablers, alongside hedonic motivation, capturing the intrinsic enjoyment and emotional satisfaction from OH engagement. Importantly, the analysis uncovers two additional constructs, educational value and recognition benefits, that significantly influence adoption intentions and community participation, suggesting essential theoretical extensions to UTAUT2 within open innovation contexts.

As for the educational value, this element points to the OH ability to democratize access to technology and cultivate STEM skills. OH, serves as a platform for skill development and innovation, enriching its ecosystem by creating a competent and inventive user base. The recognition benefits reflect rewards with community-based perspective, such as increased professional credibility, visibility, and social acknowledgment. These findings suggest essential theoretical extensions to UTAUT2 within open innovation contexts. This study contributes theoretically by enriching technology adoption literature with community-centered insights and practical implications for stakeholders aiming to enhance the accessibility, sustainability, and societal impact of OH initiatives.

Keywords: Open Source Hardware, Technology Acceptance, Open Strategies, Community Narratives, Grounded Theory, UTAUT2

1. INTRODUCTION

The open-source movement is challenging conventional roles and altering the development of technological innovation processes (Saura et al. 2023). Open source software (OSS) was originally valued for its ability to leverage pre-existing codebases and reduce resource consumption, but now it is recognized as high-quality, safe, and dependable, driving its growing adoption across industries and institutions worldwide (Ro et al. 2024; Wright et al. 2023; Wang et al. 2020). Building on the success of OSS, open-source hardware extends these principles to the physical domain by enabling public access to hardware designs for study, modification, and production from small tangible products to large physical infrastructures (Stange et al., 2023). Open hardware (OH), like OSS, has the potential to alter innovation processes by emphasizing collaboration, customization, and accessibility. Unlike traditional proprietary systems, OH allows users to openly share, adapt, and expand hardware designs, promoting societal inclusion and innovation in hardware technology development (OSHOWA, 2020). Despite the OH potential to promote sustainability and user-driven innovation, particularly in agriculture and healthcare (Moritz et al., 2018), OH faces unique challenges because of its tangible nature, such as overcoming complex licensing procedures and manufacturing constraints (Wenzel, 2023). The inclusion of open principles into hardware projects might bring numerous benefits, which involve, among others, cost savings, compatibility with existing systems, the ability to personalize designs, sense of achievement, personal joy and belonging that comes from participation in community-driven innovation processes (Shukla et al., 2023; Bonvoisin, 2016; Pearce, 2017). On the other hand, major complications can hinder its adoption, such as users' lack of technical skill, limited access to essential materials, and issues caused by legal and licensing regulations (Li and Seering, 2019). Furthermore, while OH's collaborative nature is praised like OSS, it complicates managing geographically distributed teams and ensuring long-term project viability (Guallart-Naval et al., 2023).

Despite OH represents a transformative approach to technological innovation, academic research on the factors influencing its adoption remains limited and fragmented (Reinauer and Hansen, 2021). This paper aims to fill this research gap by employing a qualitative approach grounded in the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2), and analyzing narratives from 28 podcasts that capture authentic community experiences and perspectives.

Narratives play a crucial role in understanding the dynamics of open-source movements (Jain et al., 2023) as they provide insights into the lived experiences, motivations, and challenges faced by individuals and communities. Community-driven narratives might offer a rich, qualitative lens to explore how users interact with OH ecosystems, highlighting social, technical, and contextual determinants often overlooked by traditional quantitative approaches. Moreover, these podcasts provide insightful, up-to-date information about the motivations and challenges associated with OH adoption. Unlike traditional quantitative methodologies, which may miss these nuances, this qualitative approach enables for a more in-depth interaction with the experiential information offered by OH stakeholders and developers.

This research provides a structured approach to analyze OH adoption by utilizing the main principles and constructs of Unified Theory of Acceptance and Use of Technology 2 (UTAUT 2) through the lens of social movement. Social movement theory emphasizes the importance of understanding cultural frames, or 'schemata of interpretation' (Goffman, 1974), in community-driven phenomena, where these frames help individuals make sense of their involvement and promote the diffusion of projects. In the context of technology adoption, narratives serve as a tool for sensemaking, enabling users and stakeholders to interpret, understand, and rationalize the complexities of adopting disruptive innovations like OH.

Thus, framing the research question within social movement theory underscores how OH adoption emerges as a collective effort to redefine institutional norms, mobilize resources, and legitimize OH as a socially and technically innovative system. These narratives encapsulate the collaborative essence of OH, and might reflect the diverse perspectives of developers, users, and stakeholders while uncovering recurring themes like resource accessibility, social influence, and educational value.

The study contributes to the greater conversation about innovation adoption and awareness of open-source projects by making significant recommendations for increasing the acceptance of open source projects. Furthermore, by presenting OH adoption as a multidimensional community-driven phenomenon, our research underscores the need for a comprehensive strategy that extends beyond technical complexities in addition to common motivations like cost-efficiency. The findings are expected to be highly helpful to potential adopters, legislators, educators, and hardware manufacturers who want to capitalize on OH's potential for innovation and societal impact.

2. THEORETICAL BACKGROUND

2.1 OPEN HARDWARE EVOLUTION AND ADOPTION

The evolution of OH can be traced back to the rise of OSS, which provided the foundational principles and practices that later influenced hardware development, emphasizing collaborative development, openness of design, and shared innovation (OSHWA, 2020). Early OH initiatives, such as the RepRap project for 3D printing, demonstrated the potential of open collaboration in democratizing access to technology (RepRap, 2016), and platforms such as Arduino and Raspberry Pi showed how OH may drive educational activities and empower individual innovators to emerge (Kushner, 2013). These early efforts highlighted a paradigm shift in which physical artifacts, much like software, could become "hybrid digital objects" — combining digital and physical components that evolve through open, distributed development processes (Pujol Priego & Wareham, 2023).

The collaborative and transparent nature of OH overcomes many of the restrictions of proprietary solutions. OH democratizes innovation, allowing for faster prototyping, lower costs, and better adaptability to customer requirements. For example, in the healthcare sector, OH drives cost-effective innovation and use through customizable medical equipment that improves patient care and speeds up technical development processes (Nolden et al., 2013; Niezen et al., 2016; Pearce, 2017). renewable energy solutions (Mora et al, 2020).

However, as OH matured, research such as the White Rabbit case at CERN illustrates that the distinction between software and hardware development is more nuanced than previously thought. Rather than being constrained solely by material embodiment and manufacturing costs, OH development is shaped by three structural factors: embodiment (physicality), modularity (how loosely components are coupled), and granularity (how decomposable they are). These traits influence whether a project is amenable to open source development or requires more traditional, centralized methods (Pujol Priego & Wareham, 2023). For instance, early in a project's lifecycle — when modularity is low and interdependencies are high — centralized control is often necessary. Over time, as designs mature and stabilize, more decentralized, voluntary contributions can take over, promoting a process of "liquification" that enables diverse contextual adaptations.

Despite its growth, the OH movement still faces several challenges. The physical nature of hardware imposes constraints not found in OSS, including material sourcing, manufacturing logistics and capabilities. Moreover, legal and licensing frameworks that govern intellectual property rights in open hardware development are complex and fragmented, complicating reuse and distribution (Stange et al., 2023).

The adoption of OH remains a complex and context-dependent process. Often described as a "black box", OH adoption lacks a clear generalizable understanding of what drives or hinders its uptake and its integration into various contexts (Reinauer & Hansen, 2021).

From a strategic point of view, OH is not just a form of altruism, but often a calculated move. Openness can reduce over-investment in innovation competition by revealing technical characteristics and value, what Huang et al. (2020) term the "information effect". While openness may risk imitation, i.e., "access effect", it can also strategically reduce inefficient innovation races, especially in contexts where learning costs are high and integration with legacy systems limits fast followers. These insights explain why some firms, such as those involved in high-precision, hybrid systems like White Rabbit, selectively open portions of their stack to invite contributions while maintaining control over core elements (Pujol Priego & Wareham, 2023; Huang et al., 2020).

Nevertheless, OH adoption continues to be limited by factors such as the high learning curve for physical systems, lack of standardization, and insufficient incentives for commercial stakeholders. As the hybrid

nature of many OH projects complicates traditional notions of modularity and openness, understanding OH adoption requires looking at both endogenous attributes (design maturity, modularity) and exogenous pressures (sector-specific standards, manufacturing constraints).

An integrated perspective is therefore essential for demystifying the OH adoption process. By examining the interplay between stakeholder motives, material characteristics, and governance structures, researchers and practitioners can begin to surface the hidden mechanisms that facilitate or hinder OH adoption — laying the groundwork for the subsequent analysis of podcast insights.

2.2 ADOPTION FRAMEWORKS

Adoption paths and trends of open-source systems and technologies have been extensively studied through various theoretical frameworks that offer insights into user acceptance, innovation diffusion, and ecosystem dynamics (e.g., Mészáros and Wachs 2024; Duan, 2024; Alrawashdeh et al. 2020; El-Haddadeh, (2020); Gallego et al. 2008). While mostly applied to OSS systems, UTAUT, the Rogers' Diffusion of Innovations (DOI) and the Technology Acceptance Model (TAM) proposed by Davis at the end of the last century provide a valuable lens for understanding the adoption of open-source communities.

In the DOI model, Rogers (2003) emphasizes the roles of innovation characteristics in influencing the rate and extent of adoption. He mentions five key elements: relative advantage, referring to the perceived improvement an innovation offers over existing solutions; compatibility, which concerns the alignment with existing values, past experiences, and needs; complexity, defined as the difficulty of understanding and using the innovation; trialability, the opportunities to experiment with the innovation before committing; and observability, the visibility of the innovation's benefits. The perceived complexity of managing external partnerships, as well as worries about the compatibility of open practices with current corporate cultures may prevent greater acceptance of open source initiatives (Poutanen et al., 2016). However, open-source strategies have numerous major advantages in terms of the five main features stated by Rogers.

In terms of relative advantage, open source adoption benefits such as cost savings, adaptability, and community-driven innovation are major motivators (Alrawashdeh et al., 2020; Urban and Greyling, 2015). Similarly, OH provides distinct benefits like cost savings, improved product quality, better flexibility, and higher transparency (Bonvoisin et al., 2017). These characteristics are closely related to open strategies since they enable joint value creation while lowering entry barriers. Furthermore, open source literature emphasizes the need of interoperability and scalability (Chau & Tam, 1997; Kapitsaki et al., 2017). Compatibility is especially critical in the case of OH because the products are substantial and must correspond to physical manufacturing procedures and technical regulations. Open strategies highlight the need for smooth integration across ecosystems, making compatibility a crucial factor in adoption (Baldwin & Von Hippel, 2011). Examining how OH meshes with adopters' systems and workflows, especially in technology-intensive industries, can reveal hurdles and offer ideas for improving interoperability. Regarding Rogers' (2003) third important aspect, technological complexity has been noted as a barrier in open source techniques, which is frequently overcome by professional training and user-friendly interfaces (Lindberg et al., 2024). For OH, complexity includes documentation clarity, assembly methods, and the technical skills required for adoption (such as soldering and schematic interpretation). Many open strategies rely on transparent governance and community-driven support mechanisms to reduce such complexity. Investigating how OH projects deal with complexity—via detailed tutorials, modular architectures, and user-friendly documentation—can provide useful ideas for increasing adoption rates of OH projects for both users and developers. According to the DOI model, trialability and observability are important aspects in boosting adoption. Pilot projects, real-world demonstrations, and open collaboration platforms like GitHub provide opportunities to showcase OH's potential, thereby increasing its visibility and appeal. However, issues like complexity in licensing, interoperability, and the lack of established ecosystems for OH innovation continue to hinder broader adoption (Bogers & West, 2012).

Similarly, the Technology Acceptance Model (TAM) emphasizes perceived usefulness and ease of use as critical determinants of adoption (Davis, 1989). The challenges of demonstrating tangible benefits and addressing usability concerns—such as integrating external knowledge or managing intellectual property—

may limit its appeal (Chesbrough, 2010). TAM provides a complementary perspective, focusing on perceived usefulness and perceived ease of use as predictors of adoption (Davis, 1989). TAM's constructs are particularly relevant for understanding the usability challenges in OH projects. For instance, studies by Wenzel (2023) highlight how open innovation platforms must balance functionality and accessibility to appeal to both technical and non-technical users. Expanding TAM to include community-driven aspects, such as social influence and facilitating conditions, has proven effective in studies of open-source systems (Venkatesh & Davis, 2000). This extended model is highly applicable to OH because of the community's role in providing support and resources can significantly influence adoption (Von Hippel, 2006). The social system, defined as "a collection of interconnected units engaging in cooperative problem solving to achieve a shared objective" (Rogers, 1962, p. 23), is a key element in the diffusion process, "especially in terms of the structure of the system, its local informal opinion leaders, and potential adopter perception of social pressure to adopt" (Dearing, 2008, p. 100). In OH contexts, the community-driven nature and the open-source ethos add layers of complexity to these models. Collaborative ecosystems—where contributors are not only users but also co-creators—challenge traditional technology adoption theories by blurring the lines between producers and consumers (Von Hippel, 2005).

Drawing on adoption models such as the Diffusion of Innovations (DOI) and Technology Acceptance Model (TAM), OH adoption can be understood as a process influenced by relative advantage, ease of use, and compatibility with existing systems (see, Rogers, 2003; Davis, 1989).

The inclusive and collaborative nature of OH necessitates a greater emphasis on social influence and community dynamics and these qualifications are highlighted in the Unified Theory of Acceptance and Use of Technology (UTAUT) proposed by Venkatesh et al. (2003).

UTAUT, in its first version, identifies indeed four core determinants of adoption that are not technology based but individual and community based. The first element refers to performance expectancy. Similar to perceived usefulness introduced in the TAM framework, it reflects the belief that technology improves outcomes. The second element looks at the effort expectancy. parallel to perceived ease of use, it relates to ease of use at a consumer level. The second two elements introduce a community based dimension in supporting the adoption, i.e. social influence, the extent to which social networks encourage adoption, and facilitating conditions, that means the availability of resources and support for adoption, such as aspects of the technological and/or organizational environment that are designed to remove barriers. In UTAUT2, Venkatesh et al. (2012) include price value; hedonic motivation as well, considering that fun or pleasure derived from using a technology can play an important role in determining technology accept; and experience and habit. In our current study, understanding the factors that facilitate or hinder adoption is critical for supporting the broader diffusion of OH practices. By examining the adoption of OH through the lens of the UTAUT 2, this study seeks to unravel the "black box" of adoption determinants. UTAUT 2 provides a comprehensive framework for understanding user acceptance and behavior, incorporating constructs such as performance expectancy, effort expectancy, social influence, and facilitating conditions (Venkatesh et al., 2012). These constructs are mentioned in the context of open hardware adoption as follows:

2.2.1 Performance Expectancy

Performance expectancy is a central construct in technology acceptance models. Venkatesh et al. (2003) and later Venkatesh et al. (2012) demonstrated that when users perceive significant benefits and improved outcomes from using a technology, their intention to adopt it increases. Pavlou and Fygenson (2006) provided further empirical evidence that perceived usefulness—conceptually analogous to performance expectancy—is a key driver of adoption in e-commerce and IT environments. Moreover, when technology is perceived to deliver superior performance, users' intentions to use it rise (e.g., Lin, 2011; Moore and Benbasat, 1991). Empirical evidence in OSS adoption literature (and by extension, hardware) has demonstrated that performance benefits directly influence adoption decisions (Duan et al, 2024). In OH, if potential users expect tangible benefits (e.g., customization, cost savings, or improved operational efficiency), they are more likely to intend to adopt it (CIT).

2.2.2. Effort Expectancy

Effort expectancy captures the perceived ease of use, a construct originally defined in Davis's (1989) Technology Acceptance Model (TAM). Agarwal and Karahanna (2000) further confirmed that when users find a technology easy to use, the barrier to adoption is reduced. Venkatesh et al. (2012) extended this notion in UTAUT2, showing that ease of use is positively related to behavioral intention. Empirical studies across domains from mobile banking to learning (e.g., Hsu & Lu, 2004) that support that lower perceived effort correlates with higher intention to use. Thus, if OH is seen as user-friendly and requires minimal learning effort, it should positively influence adoption intention.

2.2.3. Social Influence

Social influence, which includes subjective norms and the effect of peer opinions, has been shown to significantly affect technology adoption. Taylor and Todd (1995) provided early evidence that individuals are swayed by the opinions of significant others. In the open source arena, Hars (2002) reported that community and peer endorsements play a crucial role in motivating participation. Venkatesh et al. (2012) also integrated social influence as a core construct in UTAUT2. For OH, where community collaboration is central, social pressure or encouragement reinforces the decision to adopt the technology (e.g., Taylor and Todd, 1995). Thus, if influential figures or community networks endorse OH, users' behavioral intentions to adopt it are likely to be strengthened.

2.2.4. Facilitating Conditions

Facilitating conditions refer to the external environment and support mechanisms available to the user. Oliveira et al. (2016) showed that when users believe that they have access to the necessary resources (e.g., documentation, community help, technical training), their intention to adopt technology increases. Venkatesh et al. (2012) further underscored that facilitating conditions directly influence both behavioral intention and actual usage. Although many studies focus on software, the principle holds true for OH where fabrication and assembly resources are critical. Thus, robust community support and accessible technical resources lower perceived barriers, thereby enhancing adoption intention.

2.2.5. Hedonic Motivation

Hedonic motivation emphasizes the intrinsic pleasure derived from interacting with technology. Venkatesh et al. (2012) incorporated hedonic motivation into UTAUT2 to account for these affective responses in consumer contexts. Studies on digital gaming and mobile applications (e.g., Hsu & Lu, 2004) reinforce that when a technology is perceived as enjoyable, users' intentions to adopt it are enhanced. Moreover, Van der Heijden (2004) has shown that enjoyment and fun significantly affect technology use, especially in contexts where users voluntarily engage with creative or innovative tools, which is similar to OH processes. Also, studies in OSS adoption reveal that enjoyable and engaging user experiences can boost long-term adoption (e.g., I don't remember right now). This construct is particularly relevant for OH if the process of building, customizing, or using it is perceived as a creative and enjoyable experience.

2.2.6. Price Value

Price value is a construct that captures the trade-off between the benefits and the monetary (or non-monetary) costs of adopting a technology. Dodds et al. (1991) argued that when users see a favorable cost-benefit ratio, their intention to use a technology increases. Venkatesh et al. (2012) integrated price value into UTAUT2 to account for users' economic evaluations. Multiple studies in both software and hardware contexts support that favorable cost-benefit perceptions lead to higher adoption rates (e.g., CIT). Thus, in the open source domain where cost is typically lower than proprietary alternatives, if users explicitly perceive that they are receiving excellent value, their intention to adopt will be positively affected.

2.2.7. Habit

Habit represents the degree to which behavior becomes automatic through repetition. Venkatesh et al. (2012) incorporated habit into UTAUT2, showing that users who have formed habitual routines are more predisposed to continue using technology. Limayem et al. (2007) indicates that habit is a strong predictor of actual use and as behaviors become automatic, they reinforce technology adoption over time. Given the

iterative and evolving nature of open source projects, once users integrate OH into their routine, its continued use is self-sustaining.

2.2.8. Educational Value (Additional Construct)

Educational values capture the intrinsic benefits of learning and skill development associated with using OH. Pearce (2013) argued that OH plays a crucial role in education by enabling hands-on learning, collaboration, and innovation. Studies on open educational resources and maker culture provide evidence that technologies offering substantial educational benefits motivate users to adopt them (e.g., Kostakis et al. 2023; CIT). In addition, research in STEM education (Kolb, 1984) shows that hands-on experiences foster deeper understanding and long-term retention, directly supporting the educational benefits of OH. When users recognize that OH can enhance their professional or personal development, their intention to adopt it is likely to increase.

2.2.9. Recognition Benefits (Additional Construct)

Recognition benefits refer to the non-monetary rewards users receive—such as increased professional credibility and social standing—when they adopt a technology. Lakhani and Wolf (2005) found that contributors to open source projects are strongly motivated by reputational gains. Hars (2002) also highlighted the importance of peer recognition in open source communities by stating that increased visibility can drive sustained participation in collaborative projects. In addition, Li et al. (2025) discusses recognition as an extrinsic reward that influences users' willingness to contribute to open source projects. For OH, where the community is a key driver of innovation, recognition not only validates contributors' efforts but also encourages ongoing engagement and further dissemination of the technology. Even if these studies largely focus on software, the same dynamics apply to hardware: if users believe that engaging with OH will boost their professional profile and earn them acknowledgement, their intention to adopt is predicted to be enhanced. This effect has been supported by various studies examining social rewards in technology adoption contexts (e.g., Antoniou et al. 2022; Hausberg and Spaeth, 2020).

Applying these constructs to the context of OH enables a broader analysis of the interplay between technical, social, and legal factors, offering valuable insights into the dynamics of adoption.

3. RESEARCH DESIGN AND METHODOLOGY

This section describes the qualitative research design used to investigate the determinants of OH adoption. Using the UTAUT 2 as a framework, this study examines a curated collection of 28 podcasts to identify patterns, motivations, and barriers to OH adoption. This methodology ensures a thorough assessment of community dynamics, aligning with social movement perspectives that highlight the role of framing, collective action, and resource mobilization in driving adoption under complex conditions.

A qualitative approach was chosen for its capacity to capture the nuanced, context-specific dimensions of OH adoption. Unlike quantitative methods, which are frequently prioritizing generalizability, qualitative research allows for a more in-depth examination of subjective experiences and social events (Creswell and Poth, 2016). The decision to use internet podcasts as the primary data source in our analysis is consistent with our goal of gathering current, cutting-edge community-driven insights in the OH world. Podcasts frequently include unedited, first-hand tales from developers, community leaders, and adopters, making them an invaluable source of experiential knowledge. Narratives captured in these podcasts reflect the 'cultural frames' (Goffman, 1974) that communities use to make sense of their engagement with OH, emphasizing the collective efforts to redefine technological norms and promote diffusion.

The data collection process involved selecting 28 podcasts that met specific inclusion/exclusion criteria to ensure relevance and diversity. The podcasts were chosen based on their focus on OH adoption, featuring discussions about challenges, community dynamics, unique cases and technological implications. According to our inclusion/exclusion criteria: the podcast episodes should have an interviewee from the OH

communities, length of the podcasts should be at least 30 minutes, they should be openly presented in the web for everyone to listen and analyze, the topic should be strictly about OH-related themes, the episodes should not include just a promotion of an OH project. In addition, there were no geographical consideration or focus while selecting eligible podcasts. These episodes included perspectives, stories and opinions from developers, contributors, OH company CEOs, and end-users, providing a multifaceted view of the adoption process while maintaining comparability of each podcast since they are gathered around in the borders of community and adoption dynamics of OH. To maintain contemporary relevance, only podcasts released within the last five years were considered. The podcasts were sourced from platforms such as Spotify, Apple Podcasts, and independent OH community channels. Detailed transcripts were created for each episode to facilitate systematic analysis. Since this transcription process was critical for ensuring accuracy and enabling a thorough thematic examination of the data, the most advanced open-source transcription application of Whisper AI used.

The UTAUT 2 framework was chosen because of its broad breadth in assessing technology adoption and utilization (Sanchez et al., 2020). While UTAUT 2 has historically been used in quantitative investigations, its constructs—performance expectation, effort expectancy, social influence, enabling conditions, hedonic motivation, price value, and habit—provide a diverse lens for analyzing qualitative data. This adaptation aligns with recent calls to extend UTAUT-based research into qualitative domains to better understand complex adoption phenomena (see, Venkatesh et al., 2012).

This study adopts an abductive research approach, which bridges inductive and deductive reasoning by emphasizing the interplay between theoretical frameworks and empirical findings (Dubois & Gadde, 2002). Abduction is particularly well-suited to exploring open hardware (OH) adoption, as it seeks to uncover novel variables and relationships that emerge during the research process. Unlike strictly deductive or inductive methods, abduction allows for continuous refinement of existing theories as they are confronted with unanticipated insights from empirical data (Awuzie & McDermott, 2017). This approach aligns with systematic combining, where theoretical models are iteratively adjusted to better match reality, creating a dynamic, cross-fertilized framework. By integrating theoretical constructs with data derived from podcast narratives, the abductive approach enhances the study's ability to develop nuanced, context-sensitive insights into the determinants of OH adoption. This flexibility in methodology strengthens the alignment between empirical observations and theory, fostering logical coherence and analytical generalization, hallmarks of rigorous case research.

Thematic analysis was employed to analyze the podcast transcripts, following Braun and Clarke's (2006) six-phase framework. The procedure began with familiarization, in which the researchers immersed themselves in the data by regularly listening to podcasts and studying transcripts. The data was then coded, with segments relevant to UTAUT 2 constructs selected and labelled in a methodical manner.

Table 1: UTAUT 2 Constructs Adapted from Venkatesh et al. (2012).

Construct	Adapted Definition	Keywords for Analysis
Performance Expectancy	The degree to which using open hardware improves task performance or achieves desired outcomes.	Ease of use, simplicity, learning curve, intuitive, user-friendly, accessibility, challenges, understanding
Effort Expectancy	The perceived ease of using open hardware in various contexts.	Ease of use, simplicity, learning curve, intuitive, user-friendly, accessibility, challenges, understanding
Social Influence	The extent to which others' opinions affect an individual's decision to adopt open hardware.	Peer pressure, societal norms, recommendations, opinions, support, community, feedback, influence, adoption trends
Facilitating Conditions	The resources and support available to assist with open hardware use and adoption.	Resources, tools, infrastructure, support, training, availability, environment, accessibility, compatibility

Hedonic Motivation	The enjoyment or satisfaction derived from using open hardware.	Enjoyment, fun, pleasure, satisfaction, gratification, excitement, motivation, inspiration
Price Value	The trade-off between the cost of open hardware and its perceived benefits.	Cost, affordability, expense, worth, investment, budget, price-performance ratio, savings, economic value
Habit	The extent to which using open hardware becomes automatic behavior.	Routine, frequency, automatic, behavior, repetition, familiarity, accustomed, regular use, consistency
<i>(Additional) Educational Value of Open Hardware</i>	The intrinsic motivations of learning opportunities and skill development gained through engagement with open hardware communities.	Learning, teaching, skills development, knowledge, training, curriculum, education, awareness, engagement, exploration
<i>(Additional) Recognition Benefits</i>	The social and professional extrinsic rewards gained from contributing, such as enhanced reputation, peer acknowledgment, career opportunities, and institutional prestige.	Recognition, reputation, credibility, prestige, status, visibility, appreciation, acknowledgment, respect, community recognition, contributions valued, job opportunities, career advancement, networking, professional exposure, hiring potential

Themes are developed by identifying patterns and linkages in coded data (using NVIVO software), with a focus on recurring ones parallel with the lens of constructs gathered from the theory (see, Table 1).

These themes are reviewed to ensure that they accurately represent the dataset and they are aligned with the research objectives. Once finished, the themes were established and blended into a cohesive narrative that depicts the motivations and challenges of adopting OH. This structured technique enabled a full data analysis based on UTAUT 2 theoretical components. The theory's framework offers a structured approach to analyzing the varied nature of OH adoption. The borrowed constructs allow us to conduct a comprehensive analysis of both individual and contextual aspects that connect technical, social, and organizational dimensions. For example, the performance expectancy reflects perceptions about OH's utility like customizability, cost-efficiency, accessibility, and social influence emphasizes the importance of community endorsement like events, tutorials or gatherings for training in determining adoption decisions. By grounding the thematic analysis in UTAUT 2, this work ensures theoretical rigor and relevance while tackling the "black box" of OH adoption dynamics.

In-Depth Abductive Qualitative Analysis: In the final phase, we re-examine theoretically surprising or anomalous cases—instances where the expected UTAUT2 relationships do not hold or new adoption factors emerge. This methodology not only aligns with the study's objectives and RQ but also contributes to advancing qualitative applications of UTAUT 2, offering a novel perspective on its adaptability and utility in exploring technology adoption in open-source contexts with particular tangible products lenses.

4. FINDINGS

This section presents the findings of the study, organized around the constructs of the UTAUT 2, and includes an additional theme on the educational value of OH, which emerged as a significant adoption driver. The thematic analysis of 28 podcasts revealed nuanced insights into the determinants of OH adoption, emphasizing both the opportunities and barriers inherent in the process.

Performance expectancy appeared as a key factor of OH adoption which indicates consumers' views on the technology's benefits. Many podcast participants emphasized OH's ability to provide significant cost

reductions while also encouraging creativity through customisation. For example, developers regularly emphasized the use of OH to provide tailored solutions for specialized problems that proprietary hardware could not address. Community members stressed the broader societal impact, citing examples such as inexpensive devices and sustainable systems created using OH, as opposed to "use five years and throw it out" technology. These debates highlight the importance of performance expectancy in determining adoption, as users and contributors see actual value in using OH for personal and collective gain.

Another key concept was effort expectancy, or the ease with which OH may be used or adopted for good. Participants stated that, while OH has great promise, it typically needs a high learning curve, especially for those with low technical experience. Several participants in the podcasts emphasized the need for easier-to-use documentation, and accessible tools to remove entry barriers. Contributors, for example, expressed difficulties in comprehending complicated design files and navigating open-source platforms. These stories emphasize the necessity of enhancing access to technical resources, since streamlining the user experience could greatly increase OH adoption rate.

Moreover, the analysis of podcasts revealed that the individuals were motivated to embrace OH largely through social influence mostly by susceptibility to interpersonal influences of colleagues or friends. Many participants mentioned how community endorsement and peer recommendations influenced their decision to participate in OH projects. Furthermore, the podcasts frequently featured stories about developers and users who were inspired to contribute and adopt after witnessing the success of others in their community. The collaborative atmosphere at OH was particularly strong, with participants emphasizing the importance of group problem solving and knowledge sharing. These findings underline the importance of developing strong, supportive communities in order to promote adoption.

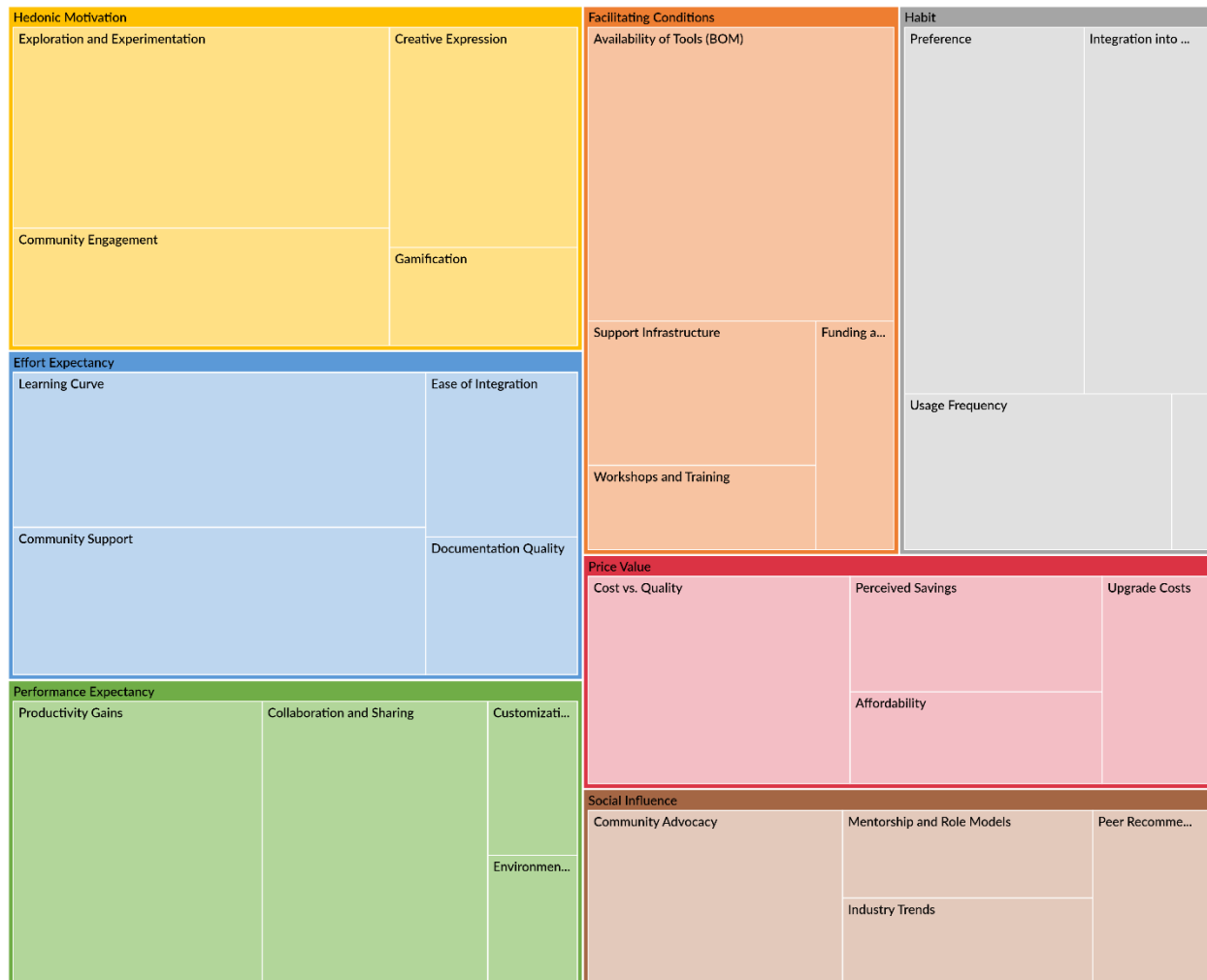


Figure 1: Hierarchy of Codes adapted from UTAUT 2

On the other hand, podcasts frequently mentioned facilitating conditions such as access to resources and infrastructure of materials. Participants are concerned regarding the availability of important supplies, such as those stated in bills of materials, as well as the logistical issues associated with obtaining them. Furthermore, discussions emphasized the significance of dependable online channels for exchanging designs and coordinating projects. For example, multiple authors emphasized the importance of platforms such as GitHub, GitLab, and the OSHWA directories in facilitating collaboration. However, infrastructure deficiencies, particularly in areas with inadequate internet connectivity or manufacturing capabilities, were recognized as major hurdles to adoption.

The pleasure of interacting within OH communities, or hedonic motivation as given in the theory of our choosing, was apparent in a lot of podcast conversations. Participants talked about the joy of making something concrete and supporting a greater cause. For example, developers discussed the excitement they get when their ideas are realized, supported, and used by others. This feeling of achievement and artistic fulfillment was often mentioned as a major driving force behind continued participation in OH initiatives. Participation's emotional benefits not only increase personal involvement but also provide a feeling of connection and community.

One of the key subjects in the podcasts was price value, which indicated the cost-benefit analysis of implementing OH. Many participants cited OH's affordability as a significant advantage, particularly for individuals and enterprises on a low budget. Examples included cheap lab equipment and teaching materials that would otherwise be prohibitively costly. Some commenters did, however, warn that even while the upfront expenditures could be lower, the ongoing costs of maintaining and improving OH systems might provide difficulties. These talks highlight how price value plays a complex role in adoption decisions by weighing possible future expenses against present affordability.

Beyond the UTAUT 2 constructs, the podcasts revealed the significant educational value of OH as an adoption driver. Participants highlighted OH's role in fostering technical skills and promoting STEM education. Some examples related to this additional finding include projects that employed OH to teach coding, electronics, and engineering principles in schools and community workshops. These kinds of

Figure 2: *Word Map Created with NVIVO Software*

associated with OH, laying the groundwork for actionable recommendations to enhance its adoption and sustainability.

5. DISCUSSION AND CONCLUSIONS

In this study we investigated the determinants that drive or put barriers in front of the adoption of OH by analyzing narratives captured in 28 podcasts by using the Unified Theory of Acceptance and Use of Technology 2 and identifying additional themes. This section's aim is to synthesize the findings, discuss their implications, and provide recommendations to increase awareness of OH projects in addition to increasing its adoption rates in the coming years of technological uncertainty.

Our study verified the importance of UTAUT 2 constructs on the understanding of OH adoption. The performance expectation construct shines as a critical variable in our analysis as participants emphasized the practical benefits of OH projects such as cost-efficiency, personalization, and social impact. These findings are consistent with the previous studies that have highlighted the usefulness of OH (Bonvoisin et al., 2017). However, achieving these benefits requires overcoming technological accessibility of logistical barriers which highlights the importance of continuous innovation and resource optimization. Another major impact was effort expectancy, which is referred to as perceived ease of use. The findings demonstrated that technological complexity and a lack of documentation remain significant hurdles, particularly for inexperienced users. These findings highlight the need of investing in user-friendly platforms, detailed guidelines, and easily available tools to reduce the entrance barrier. Streamlining the user experience may broaden the pool of possible users and increase involvement.

The role of social influence was also prominent, with community endorsement and peer recommendations acting as powerful motivators for adoption. This finding reinforces the importance of fostering vibrant, supportive communities where users can share knowledge and experiences. The podcasts underscore OH's collaborative culture, which argues that community engagement initiatives should encourage diversity and active involvement. Results confirm narratives as technological action frames (Bijker, 1997), which tie together social actors and ascribe shared meanings to OH, emphasizing its potential as a collaborative and democratized innovation tool. The narratives analysed in this study align with technology- and product-oriented movements (TPMs) (Hess, 2005), which mobilize support for alternative technologies like OH. These movements, driven by community actors, highlight the cultural and social value of OH while promoting alternative pathways to knowledge production and development.

Facilitating circumstances, such as resource availability and infrastructure, were frequently mentioned both as facilitators and restrictions. While platforms such as GitHub and OSHWA directories have improved cooperation, infrastructural gaps, particularly in areas with poor access or manufacturing skills, pose substantial challenges. Addressing these discrepancies via targeted investments and governmental initiatives has the potential to dramatically improve OH scalability and accessibility. Furthermore, the hedonic motivation, or the emotional gratification derived from OH participation, was another notable theme. Participants expressed joy and fulfillment in contributing to meaningful projects, suggesting that emotional rewards play a critical role in sustaining engagement. This insight highlights the value of recognizing and celebrating contributors' efforts to foster a sense of community and shared purpose.

The simultaneous nature of price value was clear like mentioned before with affordability seen as a significant advantage but offset by worries about continuing maintenance expenses. These findings

highlight the need of transparent cost evaluations and long-term expenditure management measures in ensuring that the financial advantages of OH remain appealing.

Habit, though less frequently mentioned, emerged as a subtle but significant factor. Regular participation in OH projects was found to build familiarity and reduce perceived complexity over time. Encouraging consistent engagement through structured programs or gamified elements could help embed OH practices into users' routines.

Beyond the UTAUT 2 constructs, the study identified the educational value of OH as a critical adoption driver. Participants highlighted OH's role in fostering STEM education, skill development, and democratizing access to technology. These findings suggest that OH can serve as a powerful tool for empowering individuals and communities, creating a pipeline of skilled contributors who can further enrich the ecosystem.

The findings broaden the use of UTAUT 2 by establishing its usefulness in a qualitative setting, notably in the realm of OH adoption. The study also emphasizes the necessity to include additional categories, such as educational value, in order to capture the complete range of adoption factors. These findings are adding to our theoretical knowledge of technology adoption by stressing the interaction of technical, social, and psychological aspects.

From the practical point of view, this current study makes numerous concrete recommendations to increase the adoption of OH. One critical area of work is increasing accessibility by simplifying technical complexities related to assembly, documentation quality, and user-friendliness. These approaches attempt to lessen the barriers for new users, making OH more accessible to those with various degrees of technical knowledge. In addition, being aware of the OH projects' educational values could give some ideas specifically to manufacturing firms and R&D departments about educating their employees by letting them contribute OH projects. Also, for the people who has electronics-relate background could benefit recognition benefits that OH projects provide for their career, community networking and self-development.

Another important recommendation is to strengthen the sense of community within the open-source hardware ecosystem. This involves investing in initiatives that foster collaboration, inclusivity, and the recognition of contributors' efforts. An inclusive, exciting and supportive community may foster more involvement, information exchange, and long-term engagement all of which are necessary for the success of each OH project. Related to the assembly of the actual hardware, overcoming resource shortages by providing alternative bill of materials is also essential for wider adoption. Expanding access to critical materials and infrastructure, especially in regions with severe poverty, may drastically decrease logistical and financial barriers. Ensuring that users have access to the relevant components and tools is critical for the successful implementation of OH projects.

Furthermore, the educational value of OH may create a big chance for its adoption. Positioning OH as a platform for STEM education and skill development can help it attract future adopters and contributors. Encouraging educational efforts and cultivating an innovative culture among learners can result in a pipeline of talented professionals who are well-equipped to work on OH projects.

Lastly, the study underlines the need for transparency in cost management and potential risks of carelessly made decisions regarding licensing regulations of OH. While cost-efficiency is frequently mentioned as the primary advantage of open source projects, identifying and addressing future

maintenance and improvement expenses is critical to guaranteeing its long-term viability and attractiveness while benefiting from its customizability and transparency. Furthermore, legal issues present a considerable obstacle to OH adoption. Open licensing frameworks, while important to OH, frequently encounter enforcement issues and conflicts with current intellectual property (IP) regulations (Stallman, 2009). The lack of uniform occupational health and safety licenses complicates problems. However, educational awareness initiatives on effective licensing practices in addition to the creation of universal licensing frameworks can help to alleviate these challenges, allowing for clearer paths to legal compliance and continuous innovation. All of these recommendations collectively provide a strategic framework for addressing the challenges and maximizing the opportunities associated with OH adoption.

On the other hand, while the study provides useful information, it is not without limits. The use of podcasts as the sole data source may introduce biases based on participant viewpoints and subjects discussed. Future research might expand on this technique with interviews, surveys, or case studies to gather a greater range of perspectives. Furthermore, investigating regional or cross-industry differences in OH adoption may give information on context-specific obstacles and possibilities.

This study underscores the multifaceted nature of OH adoption, shaped by a combination of UTAUT 2 constructs and additional factors such as educational value. By exposing adoption determinants via community narratives, the study provides an extensive framework for understanding and resolving the obstacles of OH adoption. As OH evolves, these findings provide a road map for increasing widespread acceptance and realizing its full potential for innovation, education, and societal impact.

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APPENDIX

Table 1: Descriptive Information of Selected Podcasts

Title	Podcast Reference	Interviewer	Interviewee	Highlights	Length	Online Links
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The Art of Open-Source Hardware	P1	Electronics.Dev	Steve from TsCircuit	· The pros and cons of open-source bounty programs · Challenges in microcontroller and PCB design · Insights into solar harvesting, star tracking, and home monitoring OH projects · Discussions about startup challenges and investor communications	46:16	Podcast Link
Next-Gen Test Equipment: A \$1000 Open Source Oscilloscope...	P2	Electronics.Dev	Lucas Henkel (PiMX8)	· OH PCIe connectivity democratization · PiMX8 as a powerful Raspberry Pi CM4 alternative to commercial products with AI capabilities · Modern PCB-mechanical integration challenges · Privacy concerns: OH camera systems · Real-world OH IoT challenges in property management	39:13	Podcast Link

The Incredible New Raspberry Pi Chip: RP2350	P3	Electronics.Dev	ElectronicsDev's participants from OH community	- Development workflows and debugging techniques of OH microcontrollers - Safety-critical software considerations in embedded systems - The pros and cons of various instruction sets - Personal experiences with different OH microprocessors and development tools - Discussions about OH Raspberry Pi Ecosystem	31:51	Podcast Link
Making Money with Open Source Hardware	P4	Open Hardware Manufacturing		- How to achieve a successful OH project outcomes - Licensing Challenges of OH - Comparison with OSS - Challenges of community management and manufacturing - Pros and cons of adopting OH principles	1:00:45	Podcast Link

Pricing Your Product	P5	Open Hardware Manufacturing	Stephen Haas (OH contributor)	· Risk of alienating potential customers with pricing · Discussions about how to sustain an OH business with increasing adoption rates · Importance of Digital Rights Management	1:00:10	Podcast Link
Incorporating Community Feedback	P6	Open Hardware Manufacturing		· Challenges of community management · Discussions about increasing engagement · Ups and Downs of community's comments and how to increase both developer and user base of an OH project	59:15	Podcast Link
Open Hardware Licenses	P7	Open Hardware Manufacturing	Thea Flowers (President of OSHWA)	· Discussions and examples about which licenses are best suited for what kind of OH projects · Challenges of choosing a license, copyright or patent? · Permissivity levels of variety of license types	1:25:21	Podcast Link

Leasing a Space	P8	Open Hardware Manufacturing	Lucian smth.	- Challenges of OH manufacturing - Community events and cruciality level of having a commercial real estate lease when developing and manufacturing OH - Supplier challenges related to Bill of Materials	1:31:25	Podcast Link
Open Hardware with Thea Flowers	P9	Open Hardware Manufacturing	Thea Flowers (President of OSHWA)		1:25:38	Podcast Link
Hardware Release Cycle	P10	Open Hardware Manufacturing	Opulo	- Discussions about how much more involvement needed for an OH product release compared to OSS projects - Challenges of less changeable nature of OH compared to OSS - Time between prototyping and release: increasing community engagement for wider adoption before final release	1:06:26	Podcast Link

The Benefits of Open Source Hardware	P11	Open Hardware Manufacturing		· Success criteria for an OH company · Balance between supporting community and making money · Motivations and benefits of keeping open the released OH product	32:36	Podcast Link
Sourcing: A Broad Overview	P12	Open Hardware Manufacturing		· Challenges of supply channels · How to find vendors? · How to vet them and make sure you're getting the quality part? · Duties, shipping, order quantities · Sourcing and maintaining the open communities	1:03:35	Podcast Link
Launching the Long Mill CNC	P13	Open Hardware Manufacturing	Chris Thorogood (CTO of Sienci Labs)	· How to plan OH projects' directions from the start · How to increase community engagement and respond user's expectations · Future planning after a	1:49:21	Podcast Link

				successful OH project		
Community Communication	P14	Open Hardware Manufacturing	Stephen and Lucian (Community Members from OH Manufacturing)	· Important choices for effective communication with community ·	1:16:09	Podcast Link
Ryan from V1 Engineering – OH Company	P15	Open Hardware Manufacturing	Ryan Zellars (CEO of V1 Engineering)		1:40:15	Podcast Link
Improving FreeCAD	P16	Open Hardware Manufacturing	Brad Colette (CTO of Odsel)		1:19:24	Podcast Link
Cost Downs (Reducing Costs in Your Supply Chain)	P17	Open Hardware Manufacturing	Smith Barbour (Maslow CNC)	· Discussions about the process of reducing costs in supply chain without making the product worse · Keeping steady the quality and customization options	1:09:35	Podcast Link

The Future of Food: (Re)growing vertical farming with open source automation	P18	Miriam Gradel (HardwareX)	Vijja Wichitwechkar n (MACARONS OH Project)		33:16	Podcast Link
Open Hardware Talks: Validating Openness	P19	HardwareX	Martin Hauer (OSEG), Sid Drmay and Lee Wilkins (OSHWA)	· Insights into OSHWA and Open Source Ecology Germany regarding openness and validation · Importance of Documentation · Standardization of OH certifications (IN SPEC-3105)	35:46	Podcast Link
From Gaza to Ukraine: Exploring GLIA OH Tourniquet and Scaling Decentralized Manufacturing During Conflict	P20	HardwareX	Tarek Loubani (GLIA OH) and Victoria Jaqua (Open Source Medical Supplies)	· Discussions about how to make life-saving medical equipment more accessible · Proprietary hardware vs. OH in developing countries, areas with low infrastructure or countries that are in time of conflict ·	32:22	Podcast Link

HILO Studio for Innovations in Textile Manufacturing	P21	Prof. Sanli Faez (Utrecht University, Physics Department) HardwareX	Sara Diaz Rodriguez, Natalija Krasnoperova (Co-Founders of HILO), and Lukas Schattenhofer (Open Source Ecology)	- Establishing remote workshops to increase community engagement - Importance of educational training sessions to facilitate user-driven experimentation	41:58	Podcast Link
Portable, Open Source Wireless Spectrophotometer	P22	HardwareX	Katrina Laganovska (Institute of Solid State Physics, University of Latvia)	- Motivations and Challenges of adopting OH principles while developing a product - Relative advantages and reliability of finished OH - Importance of having upper-hand when the OH product compared to a commercial product	24:18	Podcast Link
A Low-Cost Acoustic Device for Monitoring Biodiversity	P23	HardwareX	Prof. Andrew Hill and Prof. Peter Prince (Open Acoustic Devices-UK)		23:42	Podcast Link

HardwareX in the Limelight	P24	HardwareX	Prof. Joshua Pearce (Western University, USA) and Todd Duncombe (Innovation Manager at Novo Nordisk)		17:36	Podcast Link
A Co-Benefits Approach: Preserving More than One Species with Open Source Hardware	P25	HardwareX	Prof. Jack Koch (Louisiana State University, USA)	· Developing a standardized OH project for marine biology labs · Funding options for OH in the field of research (specifically US National Institutes of Health fundings)	27:46	Podcast Link
Democratizing the Air Quality	P26	HardwareX	Daniel Mauricio Pineda (Universidad Nacional de Colombia)	· Importance of documentation and comparison tests · Tailored to specific needs nature and quality assurance of OH · Relative advantages like remote data gathering and customization for wider adoption	24:23	Podcast Link

Building A Better Mousetrap: Scaling Animal Wellbeing with Open Source Hardware	P27	HardwareX	Dr. Isaac Weaver (Manager of Portfolio and Corporate Strategy at Stealth Biotech)	· Ethical and privacy considerations of OH projects · Community's importance while working for greater good · OH principles' contributions to science and research (Expanding the collaborative environment of research fields)	23:18	Podcast Link
High-Tech Prosthetics: Granting Locomotion to All with Open Source Robotics	P28	HardwareX	Prof. Filippo Sanfilippo (University of Agder, Norway)	· OH's importance on affordability, accessibility, especially in developing countries and rural areas · High probability of manufacturing a better product compared to proprietary solutions	28:31	Podcast Link

Table 2: Selected Keywords for Each Construct to Start Analysis

Main Constructs	Subdomains	Selected Keywords for Strings to Use in Analysis Software
Performance Expectancy	<i>Productivity Gains</i>	"efficiency" OR "time saving" OR "faster process" OR "streamlined" OR "improved workflow" OR "automation" OR "optimization" OR "increased output" OR "task reduction" OR "work acceleration" OR "enhanced performance" OR "operational efficiency" OR "better results in less time" OR "reducing effort" OR "simplifying tasks"
	<i>Customization Potential</i>	"customize" OR "tailor-made" OR "user-defined" OR "flexible design" OR "modify" OR "adjustable" OR "personalized" OR "custom" OR "changeable" OR "adaptable" OR "tweakable" OR "bespoke" OR "user-specific" OR "configurable" OR "parameterized" OR "fine-tuned" OR "hackable"
	<i>Collaboration and Sharing</i>	"teamwork" OR "group project" OR "shared effort" OR "co-creation" OR "open-source contribution" OR "peer collaboration" OR "collective work" OR "GitHub" OR "repository" OR "co-develop" OR "knowledge exchange" OR "idea-sharing" OR "co-working" OR "joint project" OR "public domain innovation" OR "collaborative effort"
	<i>Environmental Impact</i>	"sustainable" OR "eco-friendly" OR "green technology" OR "biodegradable" OR "recyclable" OR "reusable" OR "environmental consciousness" OR "reducing waste" OR "energy-efficient" OR "carbon footprint" OR "sustainable innovation" OR "climate-conscious" OR "eco-responsible" OR "upcycling" OR "less pollution" OR "responsible consumption"
Effort Expectancy	<i>Learning Curve</i>	"easy to learn" OR "difficult to master" OR "intuitive" OR "complex" OR "user-friendly" OR "beginner-friendly" OR "steep learning curve" OR "technical expertise required" OR "easy-to-use" OR "complicated at first" OR "self-explanatory" OR "initial struggle" OR "takes time to understand" OR "technical barrier" OR "onboarding difficulty" OR "prior knowledge"

	<i>Documentation Quality</i>	"manual" OR "user guide" OR "well-documented" OR "step-by-step" OR "instructional materials" OR "poorly written" OR "tutorial" OR "handbook" OR "clear instructions" OR "missing documentation" OR "detailed explanation" OR "technical manual" OR "API reference" OR "learning materials" OR "structured guidance" OR "FAQ"
	<i>Ease of Integration</i>	"plug and play" OR "seamless" OR "compatible" OR "interoperability" OR "well-integrated" OR "smooth transition" OR "third-party support" OR "easily combined" OR "adaptable system" OR "works with other platforms" OR "modular" OR "pre-built" OR "out-of-the-box compatibility" OR "well-connected" OR "integrated framework" OR "hassle-free setup"
	<i>Community Support</i>	"forum" OR "online help" OR "knowledge base" OR "Discord server" OR "support group" OR "Stack Exchange" OR "issue tracker" OR "troubleshooting" OR "online assistance" OR "FAQ section" OR "developer community" OR "peer support" OR "user forums" OR "technical help" OR "open-source network" OR "guidance from others"
Social Influence	<i>Peer Recommendations</i>	"word-of-mouth" OR "referred by others" OR "personal endorsement" OR "friend recommendation" OR "highly rated" OR "testimonial" OR "reviewed by peers" OR "personal experience" OR "success story" OR "known among colleagues" OR "positive feedback" OR "user testimonials" OR "industry approval"
	<i>Community Advocacy</i>	"enthusiasts" OR "evangelists" OR "open-source movement" OR "grassroots support" OR "community-driven" OR "passionate users" OR "long-time adopters" OR "core developers" OR "project ambassadors" OR "ecosystem growth" OR "collaborative efforts" OR "active supporters" OR "volunteer contributors" OR "user-led growth"

	<i>Industry Trends</i>	"market adoption" OR "emerging technology" OR "widely used" OR "mainstream adoption" OR "tech trend" OR "growing interest" OR "innovation cycle" OR "industry standard" OR "trending technology" OR "competitive landscape" OR "popular solution" OR "disruptive innovation" OR "rising in popularity" OR "state-of-the-art"
	<i>Mentorship and Role Models</i>	"guidance" OR "mentorship" OR "industry leader" OR "expert advice" OR "role model" OR "experienced users" OR "coaching" OR "technical mentorship" OR "learning from others" OR "well-known developers" OR "professional guidance" OR "inspiration" OR "best practices" OR "tech influencers"
Facilitating Conditions	<i>Availability of Tools</i>	"accessible" OR "easy to get" OR "available resources" OR "hardware supply" OR "software support" OR "toolkits" OR "equipment ready" OR "pre-built modules" OR "hardware vendors" OR "sourcing components" OR "procurement" OR "technical accessibility" OR "easy-to-source" OR "open-access"
	<i>Support Infrastructure</i>	"help desk" OR "online support" OR "structured guidance" OR "training sessions" OR "help articles" OR "customer support" OR "tech assistance" OR "troubleshooting help" OR "system support" OR "framework assistance" OR "after-sales service" OR "in-house help" OR "educational resources"
	<i>Workshops and Training</i>	"seminars" OR "bootcamp" OR "educational training" OR "hands-on workshop" OR "technical course" OR "guided training" OR "lab exercises" OR "skill development program" OR "technical coaching" OR "hackathons" OR "interactive learning" OR "certification program" OR "real-world application" OR "structured learning"
	<i>Funding and Sponsorship</i>	"grants" OR "financial backing" OR "investor support" OR "crowdfunding" OR "academic sponsorship" OR "funding" OR "donations" OR "financial aid" OR "research grants" OR "economic feasibility" OR "subsidized projects"

		OR "partnership funding" OR "sponsorships" OR "backing from organizations"
Hedonic Motivation	<i>Creative Expression</i>	"artistic" OR "design freedom" OR "experimenting" OR "personal projects" OR "unique designs" OR "innovative use" OR "self-expression" OR "creativity" OR "pushing boundaries" OR "aesthetic appeal" OR "individuality" OR "unconventional applications" OR "expression through technology"
	<i>Community Engagement</i>	"forum discussions" OR "meetups" OR "hackathons" OR "contribution culture" OR "social events" OR "conferences" OR "peer networking" OR "open-source communities" OR "user gatherings" OR "community projects" OR "joint efforts" OR "collaborative spaces" OR "discussions" OR "teamwork spirit"
	<i>Exploration and Experimentation</i>	"prototype testing" OR "trial and error" OR "discovery" OR "new ideas" OR "hands-on" OR "exploring possibilities" OR "research phase" OR "sandboxing" OR "unconventional use" OR "pushing limits" OR "trying new things" OR "experimenting with features"
Price Value	<i>Affordability</i>	"cost-effective" OR "affordable" OR "budget-friendly" OR "low-cost" OR "economical" OR "cheap" OR "price-conscious" OR "financial advantage" OR "cost savings" OR "low entry barrier" OR "reduced expense" OR "inexpensive" OR "reasonable price"
	<i>Cost vs. Quality</i>	"value for money" OR "performance per dollar" OR "trade-off" OR "cost-efficient" OR "return on investment" OR "price-performance ratio" OR "worth the cost" OR "quality justified" OR "investment-worthy" OR "effective use of funds"

	<i>Cost of BOM and Upgrades</i>	"expensive add-ons" OR "additional investment" OR "premium features" OR "extra costs" OR "upgrade expenses" OR "recurring costs" OR "further investment" OR "cost creep" OR "optional upgrades" OR "required purchases" OR "hidden expenses"
	<i>Perceived Savings</i>	"cheaper than alternatives" OR "free alternative" OR "money-saving" OR "low-cost solution" OR "alternative to expensive options" OR "best value" OR "avoiding high costs" OR "total savings"
Habit	<i>Usage Frequency</i>	"daily use" OR "regular usage" OR "every day" OR "frequently used" OR "ongoing" OR "habitual" OR "routine use" OR "long-term adoption" OR "repeatedly used" OR "frequent engagement"
	Preference	"favorite tool" OR "go-to" OR "always use" OR "preferred choice" OR "personal preference" OR "default option" OR "trusted solution" OR "first choice" OR "primary option"
	Integration into Workflow	"part of the process" OR "incorporated into work" OR "everyday tasks" OR "fits into work style" OR "seamless part of daily routine" OR "essential tool" OR "daily habit"
	Community Rituals	"shared experiences" OR "repeated practices" OR "recurring patterns" OR "user traditions" OR "habitual engagement" OR "customs" OR "established behaviors" OR "well-known routine" OR "ongoing involvement"

Table 3: Selected Quotes from Podcasts

Construct	Selected Quotes on First Order Codes in Podcasts
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Performance Expectancy

"I've seen of the performance comparisons of "risk five" versus commercial and still passes it every day yeah obviously the tool chain support and the compiler support is way better" (P1)

"...the same price but better performance and easier to use like that's my only goal is be very frugal with pricing and all choices have to lead to easier or better" (P16)

"it's customizable definitely once you have the design in your hand you can customize it to your need to your geometry or to the experimental environments that different projects demand" (P19)

"But to bring this to the market, it will be crucial, it will be helpful if a standard would exist in terms of requirements or expected performances so that you can compare your prototype with other competing devices." (P20)

"It will be helpful if a standard would exist in terms of requirements or expected performances so that you can compare your prototype with other competing devices" (P24)

"you have the hardware right you have the instructions to kind of put the hardware together also here's how you can very easily code it you can now very easily code new functionalities to it without really needing to understand the nitty-gritty details of how the code works until you get to that point the adoption of this type of technology would be slow because the entry barrier is quite high but the moment you can kind of like almost productize it into this system where it's easy for you to kind of hack and create add new sensors and new functionalities until you get there" (P25)

"...it's all customizable you can change that all if you want to can make it really your own and that's exactly what I'm in the process of doing right now" (P27)

Effort Expectancy

"This is probably extremely easy where you have kind of a debug module and you can kind of plop it in there and then it's like it really wasn't that much effort and you have a world of debug ability and yeah i mean that's pretty cool and you can it it's like the alternative to add a bunch of test points" (P2)

"..there any other like hardware specific licenses like cern ohl is kind of the only one that I'm aware of that is very specifically suited towards hardware design there are a couple, there are at least a couple of more like more of them like cern was not the first to take a stab at it but they're the ones that took a very concerted effort with the help of like actual legal experts that are that are familiar with hardware to draft this right" P(3)

"... the amount of effort to get from no contribution to a contribution is tremendous, yeah the scale of the contribution still does matter it's like it's a metric right but the fact that they put a foot forward" (P4)

"when there is a limited way a limited amount of ways that you can express a specific circuit it becomes vanishingly hard to enforce copyright on that right, for example I can write up a schematic right now in kycad and I could use my fancy page layout that I have and I can draw a non-inverting buffer schematic right and I could publish that I could license it and if someone tried to copy that file as is and redistribute it i could technically you know bully them about it" (P5)

"you probably don't want that to be you know a viral license like copyleft sort of situation because you don't want every project that uses that to have to be that way right exactly yeah it's also really easy to just reimplement and not have to use it so you're not going to get a lot of people using that license or that that thing too well yes but like yeah it'll also throw up barriers to adoption right where it is" (P8)

"...your company should have a mission of like doing something cool and like ours is helping people manufacture their products it's all for that any profit we make goes into investing in r&d in a project you have one working on right now that is going to make things a ton better that money goes to improve stuff it's still towards the mission so like you do want to make money that's a company we live in the world where you have to do that, as an organization if you're trying to do something like this but like you do it with your customer in mind like you want to perpetuate yourself in this organization but you don't want to do it at the expense of your customer, ultimately your goal should be to help them do something yeah and like they should see where their money goes" (P10)

"it's really hard, it takes a lot of discipline but like you have to be really self-critical this is a business you can't do the thing that feels fun and exciting you have to do the thing that's going to work for the organization how you react to growth and success needs to feel like a no-brainer yep you can gamble you can be a little risky but it just all needs to be modeled exactly you have yeah you have to understand exactly you can't do it blindly you can take risks we still do we still will take risks but it has to be something that you have reasonable confidence is going to be successful" (P11)

"I almost want to say that the wiki is for how to use the github repo right i think you're right yeah it almost would feel inappropriate if docs at opulo covered a contribution guide for the lumen pmp the open source project right because the docs are how to use the lumen and the wiki is about how to use the github the wiki tell us people how to be a good contributor to the source how to be a good steward of the community how to join the community how to make it easy and emerge and review and all that" (P14)

"So the thing is that there are devices on the internet that you could copy. However, it comes more like how easy it is to reproduce them. Some of those devices require a level of skills that not everybody has. I try to put the device, the research, in a way that even if you don't have very high knowledge in electronics and programming, you could maybe ask someone for a little bit of help and then reproduce the device" (P28)

Social Influence

"I think that's a really cool thing you know i think it's cool you're not doing it you're not doing it for altruism you're doing it because it's the right way to work ultimately it produces a better thing both reasons like i i like the ethos of it being open a lot but also yeah i mean just like you said you know Ondsel plus a huge army of contributors" (P16)

"... But the only way that that standard gets out is if we're making it open, if other people can easily adopt it. I think about Tesla with the car charging port they've been putting out there. It's open source. They encourage other people to use it. They encourage other people to make cars that work with their chargers even. And they can't stop people from copying that connector.

So they might as well just embrace it." (P19)

"...those were our early adopters. And that's also pretty much the, at least the most vocal people in our community. But most of the sales that we have of the machine are people who want it for us doing useful manufacturing work for their company. And there's a lot of those people on our server too, but, you know, balancing like the people who want it for the hobbyist project to hack around and have a cool platform to do hackery and improvements." (P20)

"We advance open source hardware so more scientists, researchers, citizens and also companies can adopt it like i said i have i was trained as a biologist and now here I am creating something that I thought up one evening that i could um you know solve a biological problem with no engineering background. I don't know an engineer might look at it and be like well why do you do this decision right so i think building networks of diverse people and with diverse backgrounds is the way forward for open hardware, and making sure that people everybody in elementary middle to high school gets exposure to these sort of things early on um even in college right so it'll be very very very powerful for the future of the world" (P25)

<i>Facilitating Conditions</i>	"Overarching theme here of like keeping the community aligned so that they give you the right feedback you want right they help make the right thing the first time around right or close to it down the right path you know yeah it's really important and it's respectful of their time yeah and energy like help them out they're trying to help you out" (P3) "...It is such a beautiful user interface um you know it is it's much easier to onboard for hobbyists than some of the other commercial alternatives and so yeah when they pulled the rug out from people they came flooding in and were frustrated with free cad's user interface and so it was like you know we're going in a direction we might as well get used to it and start working on it yep yeah exactly"(P16) "with accessible hardware and software you will accelerate research in that way in in the way that it's accelerated my research right if open hardware with macarons become gets to that level i think we'll see more adoption of it and more automated plant science experiments so accelerating research and in the sense then also accelerating innovation for the industry potentially also by feeding it back and creating multiple branches and directions that it can go" (P18) "the power of open source hardware is that it benefits everybody involved it's not just the community giving ideas they are also receiving solutions and designs and so on but a large part of the success of open source hardware comes down to documentation and that's a quite kafka-esque topic sometimes" (P26)
<i>Hedonic Motivation</i>	"So we did really well open source was fairly core tenet when we were making the device just because it makes it a lot easier to adapt uh and adopt in places where uh building the device yourself is a lot more achievable than obviously ordering it from another country and bringing it in and it also encourages more technically minded users to like innovate" (P23)

<i>Price Value</i>	"maybe people aren't buying it because it's too expensive and you need to bring the price down and sell more of them or you know there's other things that need to happen maybe you're you're running on vc money and you want to operate at a loss for a while that's okay too one of our mentors originally suggested to us that adoption was almost a more important metric than like the profit per machine and uh this person even suggested that the machines aren't sold for a profit yeah just to just to the idea of like seed the world with tens of thousands of lumens exactly like a loss leader amount right yeah because what's going to help grow community" (P2) "where you can reduce your cost to the overall product and this can be in terms of material cost it could be shipping cost labor cost operational expenses even labor cost does labor cost yeah anything's a cost down that's fair if you think about it from the whole top down perspective yeah that's fair" (P1) "the need for research and having something that is accessible customizable relatively cheap um can make your research dollars go a lot further than they normally would and if you can create it yourself then you can you know again make you can make it customized to exactly what you need rather than have to buy an off-the-shelf product that is intended for one purpose and you repurpose it for something else um and then this community idea you know having a thousand people working on a problem is a lot better than having one or two and so that's what we're trying to build with open hardware and science is this large community that um all works together on big problems um or diverse problems" (P26)
<i>Habit</i>	

*(Additional)Educational
Value*

"I've had to learn things from a more hands-on practical perspective and then fill in the gaps with self-learning on concepts and higher levels right yeah and you know that's something that lasts for your whole life and not just the four years of college like if you rely on learning from a professor you're done after four years or you have to pay for another thing" (P9)

"I like about programming was you get to learn all sorts of stuff sure and I fell into this the maker community and these people were teaching me about machining and teaching me about they're like we should make something make some open source software and so we started contributing to an older project called heaks cad, kind of died and along the way we met some of the people in the free cad community and so we said well let's go over there hang out with those guys and see if we can make this work" (P16)

"The closed source cads are you know they're very strategic about you know getting curriculum written and getting free licenses into student hands and getting classes actually structured so you're not teaching design principles you're teaching fusion yeah right and now that so a student comes away knowing that tool and only that tool right that's got to change before you can really get widespread adoption" (P17)

*(Additional)Recognition
Benefits*

"no matter how small a contribution may be to the person who added it might be a major section on their resume it might be a 15 minute discussion that in a job interview that gets them their dream job yes it's really important to celebrate this stuff and to like recognize it" (P6)

"reciprocation's been kind of a big topic going around especially like the 3d printing community yeah and i have a lot of thoughts about it good and i have a lot of and like ultimately it boils down to like i think people generally have a very narrow definition of reciprocation uh where it's you know like using the software analogy where it's like pull request right you know send a pass yeah no historically that's been reciprocation in software but I think especially with hardware reciprocation can be so vast yeah and a lot of the times something that can be seen as reciprocation is taken as an affront or stealing and I think that you know and this goes back to like you know my response to prusia and you know some of my general thoughts about you know the 3d printing ecosystem right now and stuff like that where it's just like there is a lot of ways that companies that people can reciprocate can add value to an open source project and its community" (P9)

"...they're still giving you that gift of feedback of information of expertise so like do everything you can to pull that in and showing other people that you do that means you're also perpetuating a community that is open to the idea of giving feedback which is exactly what you want so you know you kind of have to walk the walk here" (P7)