Towards Improving the Usability of Password Managers

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Abstract. Security experts strongly recommend the use of Password Managers (PMs). However, PMs are not widely used and studies indicate usability problems and distrust from users as the reasons for their low adoption. In this paper, we review usability challenges of PMs and we propose the use of known usability best practices and techniques to extend and improve Bitwarden, a widely-popular open-source PM. Since this work is done in the context of the PassCert project, which aims to build a formally verified PM, we also investigate ways to effectively convey to users the formally verified properties. We report on preliminary results and we propose a methodology to evaluate our extension of Bitwarden and to determine the impact of formal verification on the adoption of PMs.

Keywords: Usable Security · Password Manager · Formal Verification · Password Security

1 Introduction

As Whitten and Tygar pointed out in their seminal work, security mechanisms are only effective when used correctly [24]. For example, effective use of text passwords, one of the most used security mechanisms [12], requires not reusing them across different services and not choosing simple, easy-to-guess passwords. However, this presents a challenge for users. In a study by Stobert et al. [22], only one of the 26 participants reported not reusing passwords between accounts and 73% reported reusing passwords either "always" or "frequently". Not only is password reuse a problem but users also struggle with choosing good quality passwords. Gaw et al.'s study [9] about password usage found that 51.79% (of 56 users) believed that a friend had a higher chance of guessing their password, suggesting that they used non-random passwords with personal information.

It is in this context that Password Managers (PMs) become an essential solution. Security experts and several governmental institutions, such as the European Union Agency for Cybersecurity [5], strongly recommend the usage of PMs that combine secure password storage and retrieval with random password generation. These tools can improve account security by enabling the use of strong and unique passwords, simultaneously improving the usability and convenience of text password authentication.

However, despite PMs being recommended, they are not widely used [1]. Several studies tried to find the reasons for this phenomenon and have reached different conclusions: some state users' unawareness of the existence of PMs [1, 16, 22], lack of trust [13, 17] and lack of motivation [1, 17]. One common factor that was mentioned by all studies was usability problems [1, 2, 4, 15, 16, 20].

In this paper, we review usability challenges of PMs and we propose the use of known usability best practices and techniques to extend and improve Bitwarden [3], a widely-popular open-source PM. Since this work is done in the context of the PassCert project[3], which aims to build a formally verified PM, a novelty of our work is the investigation of ways to effectively convey to users the formally verified properties and whether formal verification increases users' trust in PMs. We report on preliminary results and we propose a methodology to evaluate our extension of Bitwarden and to determine the impact of formal verification on the adoption of PMs.

After presenting the usability challenges of PMs in Section 2, we present in Section 3 best practices for improving usability. In Section 4, we discuss usability problems in the context of Bitwarden and concrete actions that can be taken to address these in our proposed extension. In Section 5, we present preliminary results and the plan to further evaluate our work. We conclude the paper in Section 6, where we also discuss future work.

2 Usability Challenges of Password Managers

The usability of PMs is an important aspect that can increase their adoption and that has been studied by the research community. In this section, we present and discuss usability challenges documented in the literature.

2.1 Password Manager Usage

Stobert et al. [22], in a study about password usage, were surprised to find that none of their participants used a dedicated PM and that most of them were unaware of popular PMs. Furthermore, a few participants expressed distrust in PMs. The authors suggested that a good integration of PMs into operating systems and browsers would help with visibility and trust.

More recently, Pearman et al. [16] studied the usage of PMs and other password management methods. A 30-participant interview study was conducted with users who do not use PMs at all (9 people), who use PMs built into their browsers or operating systems (12 people), and who employ separately installed PM application (7 people).[4] The study found that **people who do not use PMs** rely mostly on memory or unsafe methods (e.g., saving on Excel sheets). The reason for not using PMs was mostly **unawareness** of their existence.

In this study, one of the major complaints was related to a **lack of awareness of how the tool and its security worked**. By not understanding the features

[3] PassCert Project Homepage: `https://passcert-project.github.io`

[4] Two participants "were difficult to place in the aforementioned categories" [16]

offered, some users could not, for example, synchronise passwords between devices. This lack of information also made the users wary of PMs' security. These findings were also backed by the work of Ion et al. [13] where non-expert users expressed a lack of trust in PMs. The motivation for users of separately installed PMs was primarily security and even though some reported poor usability (e.g., difficulty navigating the interface), they were satisfied with the security provided.

Convenience, usability, and security were the main concerns raised in this study and a problem identified was the users' lack of information regarding how PMs work. The study calls for better usability testing and focus on non-experts.

2.2 Password Manager Usage with Older Users

The participants in Pearman et al.'s study were skewed towards young people, with a high percentage of participants with technical backgrounds. As such, Ray et al. [17] expanded Pearman et al.'s findings by replicating their protocol and interview instrument but applied to a sample of strictly older adults. A 26-participant interview study was then conducted with older adults (aged above 60) who do not use PMs at all (10 people), who use PMs built into their browsers or operating systems (9 people), and who use separately installed PMs (7 people). Across all, secure access to financial accounts was valued above other types of online accounts. Regarding users that do not use PMs, both older and younger adults were concerned about **a single point of failure** when using PMs (e.g., losing access to all passwords stored). Concerning the participants that used browser built-in PMs, both older and younger adults were worried about others having access to their passwords and about where they were stored. Similar to the findings of Pearman et al., users who adopted separately-installed PMs were motivated by their desire for better security.

Lack of self-efficacy when dealing with software was one of the main barriers to the adoption of PMs. A higher level of transparency (e.g., showing users how secure their passwords are) could also help towards increasing trust [17].

The suggestion given by Ray et al. was to encourage advocacy, particularly from family or friends, but also by trusted organizations. Another suggestion was education to convey urgency of secure practices (e.g., classes at senior centers). Erroneous and **incomplete mental models** of how PMs work (e.g., encryption, cloud storage, etc.) also surfaced in this study [17].

2.3 Password Managers in Smartphones

Usability in smartphones presents different challenges from conventional desktop interfaces. For example, in a study focused on PMs for mobile devices by Seiler-Hwang et al. [20], users' unawareness of the existence of PMs was not a rejection factor, as most of the participants knew about them. Seiler-Hwang et al. conducted a usability study comparing 4 popular smartphone PMs (Dashlane, Keeper, Lastpass and 1Password) with 60 participants. They used the *System Usability Scale (SUS)* to compare the PMs' usability. Overall, looking at the small sample of analyzed applications, PMs appear as software tools that can be

subjectively considered "ok", but far from being "excellent" [20]. Participants often complained about **lack of guidance**, instructions, tutorials, or help pages. This meant that sometimes they were unable to achieve their goals within the PM. Also, for participants that were unfamiliar with PMs, this lack of guidance is translated into a lack of understanding about how PMs work. Finally, one of the most problematic areas identified in the usability of mobile PMs was **poor integration** with other applications and browsers.

Alkaldi et al. [1] investigated the factors impacting the adoption or rejection of smartphone PMs based on Play Store and App Store reviews. They found factors such as **awareness, no perceived usefulness, security, and privacy concerns** to be detrimental to the adoption of PMs. They state that even if people become aware of the apps, they might still not embark on a search process to consider installing one. Failure to reassure potential users about the trustworthiness of PMs was identified as a main factor behind their rejection.

2.4 Comparative Usability Studies

A comparative analysis of PMs usability and security was conducted by Arias-Cabarcos et al. [2] on five different mainstream PM applications. For the usability study they used a set of evaluation criteria known as the 5 Es (Efficient, Effective, Engaging, Easy to learn and Error tolerant). Although the PMs studied did not have negative ratings of usability, important differences arose when users rated PMs according to the engaging and easy-to-learn features. An interface is engaging if it is pleasant and satisfying to use and it is easy to learn if it allows users to learn without effort. KeePass was the worst evaluated manager in both these categories [2]. The best rated PM, in all categories, was Dashlane.

A usability issue related to the users' **mental maps** was about the tools' activation. Users believed that the PMs would, after an initial activation, stay working for the rest of their computer session. Inconsistency in the interface of the PM also hinders the mental model of the users. For example, this was observed in PwdHash, one of the PMs studied by Chiasson et al. [4], where a specific command was irrelevant as it would give the same output whether it was used or not.

Not all usability problems encountered by Chiasson et al. were a direct result of the PMs' interfaces. Some problems were due to bad website design. These are valid usability issues that provide context and insight into the circumstances and environments where people will be using PMs.

Control was also an important issue for users. When the PMs on the study did not show the passwords that they were generating, users felt frustration as they felt as though they had no control over their passwords.

A major problem arises from the developers' assumption that users will use the tool correctly. This is problematic as new users frequently commit mistakes and may be deceived into thinking they are safe when they are not. If the systems are very secure but do not have good usability, users may opt to use a different, less secure system that lets them do what they want [19].

3 Improving the Usability of Password Managers

As we have seen in the previous section, PMs have usability problems that need to be addressed. Additionally, given PassCert's context, we consider a new set of challenges related with how information about formal verification is conveyed to users. This section presents best practices and possible solutions to address these challenges.

3.1 Usability Improvements

There are general design guidelines that can be followed to improve the usability of PMs. For example, a guideline to follow is Shneiderman et al.'s *Eight Golden Rules of Interface Design* [21]. These are intended to be used during design of systems [6]. Another good practice is *security by default*: to have default configuration settings that are the most secure settings possible [20]. This is particularly helpful for inexperienced users as they may not understand the meaning of every setting in the interface. A **well-integrated software** with bug-free features is also essential to enable users to create clear mental models of the tool [4, 20]. To achieve this, software and usability tests, and formal verification can be used. A good software has to have a clear navigation and be error tolerant (this is especially important for new users). It should be permissive and allow the users to recover and learn from mistakes [8].

Table 1 summarizes usability challenges concerning PMs and proposed solutions. Regarding the proposed help documentation and tutorials, it is important to to avoid the use of technical jargon [8, 18]. Moreover, explanations of the different security options can be achieved through the use of tooltips [8] and help icons.

3.2 Information on Formal Verification

It has been shown that formal verification is valuable when considering password security [7, 14]. Since this work is done in the context of the PassCert's project, which aims to build a formally verified PM, a novelty of our work is the investigation of ways to effectively convey to users the formally verified properties and whether formal verification increases users' trust in PMs. Therefore, a primary concern we have is **educating the users about formal verification**. This can be achieved by implementing the following:

- Provide a clear way to understand what properties the system is formally assuring with status symbols to indicate that a certain action is formally assured [8].
- Concise explanations about formal verification. It is important to use correct and simple language in order to prevent alienating users (e.g. avoid the use of jargon and unnecessary technical language) [8, 18].
- Further information may be required by the more inquisitive users and it should also be provided. This can be done by providing links to expanded documentation and further resources.

Table 1. PMs' challenges and proposed solutions

Challenge	Proposed Solution	Description of Solution
Lack of trust and understanding [13, 17, 20]	Provide a higher level of transparency (e.g., showing users how secure their passwords are)	– Educate users about how PMs' work [20]. – Advocacy from trusted organization about the use of PMs (e.g., schools) [17].
Lack of motivation to use PMs [1, 13, 17]	Educate users about the benefits of using a PM	– Provide information related to the dangers of unsafe password habits [4, 13, 16], and about the increased productivity and security of using PMs [13].
Bad performance, poor integration with other applications and browsers [20, 22]	Solid implementation of all PM's features	– Functionalities like password generation, auto-fill, and device synchronization are core and need to be well implemented [20]. – Usability testing of the PMs and their integration with other applications and browsers [20, 22].
Difficulty of use (lack of usability) [1, 2, 4, 15, 16, 20]	Simplify the interface and provide support for users	– Tutorials about how the interface works (for beginner and expert users). These should be naturally integrated with the interface to be promptly accessible when required, but should not interfere negatively with the user experience [20]. – Explain what different options in the security settings mean [20]. – If users are unsuccessful, feedback should be short and help them address the issue [4]. – The PM should be error tolerant: this is especially important for new users. The PM must be permissive and allow the users to recover and learn from their mistakes [2].
Inadequate Mental Models [4, 13, 17]	Provide a precise interface	– Give feedback to users about the status of their actions (if they were successful or not) [4]. – Navigation should be as clear as possible [8, 19].

4 Extending Bitwarden

The PassCert project is using Bitwarden as a basis for creating a proof-of-concept PM that through the use of formal verification, guarantees properties on data storage and password generation [10]. Therefore, as the work presented here is done in the context of PassCert, our goal is to improve the usability of Bitwarden and explore how it can effectively convey information about the formally verified properties. This section starts by presenting usability problems of Bitwarden. It then describes several extensions already implemented and preliminary results.

4.1 Bitwarden Usability Problems

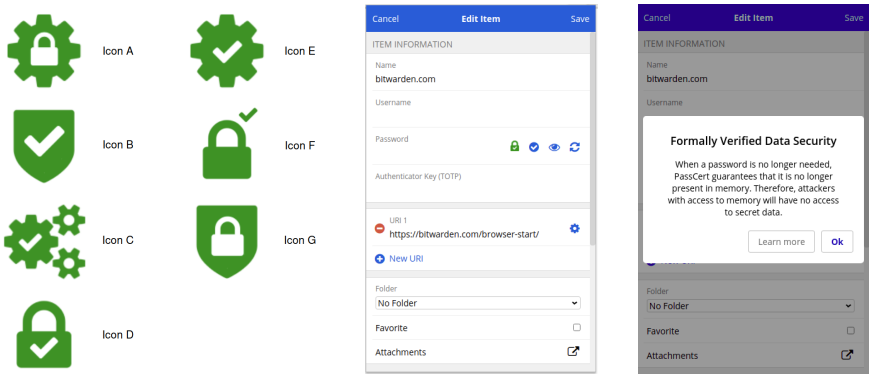
A thorough analysis of the Bitwarden interface was conducted and, considering the information presented in previous sections, the main problems found were:

- **Lack of user support.** Bitwarden does not provide access to any tutorial, which is something that participants in previous PM studies asked for [20].
- **Lack of consistent tooltip information.** Some settings had no support or tooltips associated, making it more difficult to understand some features (e.g. the input box "Authenticator Key").
- **Lack of consistent behaviour.** We found inconsistencies in buttons that look the same but present distinct behaviors. Inconsistencies in interfaces can hinder users mental models [4, 21].

4.2 New Icon Signalling Formal Verified Features

To help users become aware of the formally verified features of the PM we designed new icons to represent formal verification. We use icons because Wiedenbeck [25] suggested that users have less favorable perceptions of text only UIs. When designing new icons is important to have an unified design [23]. To ensure this, we used the same font that Bitwarden's existing icons use. Moreover, we considered variations of existing or familiar icons (see Figure 1(a)). Some of these may serve as metaphors for security. Interface metaphors are important to convey information [21, 23]. The icon design process went through several iterations, a brainstorming session, two rounds of feedback from the team, and lastly, feedback from users outside the team. The feedback form was composed of an attractiveness test where users chose the icons they like more without context, followed by a preference test where we explain what the icon is trying to convey and ask users to rate it by preference [11].

Explanations about formal verified features. The formal verification icon is distributed throughout the interface where a feature is formally verified. When clicked, it opens a contextual description about the formal verification of that specific feature (see Figure 1(c)). These explanations were designed in two iterations: a first definition of the features was written and improved over two rounds of feedback from the PassCert team that is implementing them. We aimed to keep the language simple and without jargon to facilitate understanding [8, 18]. An example, related with a data security property, is illustrated in Figure 1(c).



(a) Icon variations

(b) Formal verification icon in the password vault (green icon)

(c) Pop-up after clicking formal verification icon

Fig. 1. Formal verification icon and subsequent pop-up

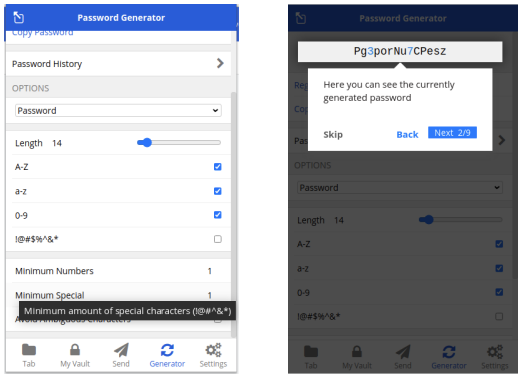
4.3 Additional Information via FAQs and Tutorials

As mentioned before, when users are using the PM they may want to learn more about certain aspects. To convey information about relevant topics, we designed a FAQ to be embedded within the PM. Although Bitwarden already provides help pages, these are exclusively online. On the other hand, our FAQ is accessible even when users want to access their passwords (and PM) offline. To implement the FAQ we followed Redish's [18] recommendation of going through every topic of interest and providing questions and answers for them. Users can access the FAQ pages from the "Settings" tab or by opening the formal verification icon, and clicking "Learn More" (see Figure 1(c)).

We also implemented a tutorial for users in the form of a walkthrough, which guides users through how the application works. This is in the form of a layer on top of the application [23]. The walkthrough implemented goes through the main sections of the PM: current tab, vault, password generator, and settings. Figure 2(b) shows an example step of this walkthrough (password generator).

4.4 Improved Tooltips

As stated in Section 4.1, Bitwarden's native tooltips can improve. We categorized existing tooltips as **Well implemented**, **Non-descriptive**, or **Missing**. Examples of **non-descriptive** tooltips were found in the bottom toolbar used to navigate in the PM. For instance, the tab "My Vault" has an icon and a label, which is a good practice according to Wiedenbeck [25]; however, its tooltip has the same text as the icon label. This does not help the user as it is redundant. All these tooltips were replaced with more descriptive ones. Lastly, there were some tooltips **missing**, such as the one illustrated in Figure 2(a).



(a) Tooltip implemented for the "Special Characters" button

(b) Example of the page tour

Fig. 2. Interface extensions: tooltips and tutorial walkthrough

4.5 Lack of consistency

Inconsistencies were found in the behavior of certain buttons that redirect the users to Bitwarden's website. These buttons are in the settings tab and can be separated in two groups: the first group includes the buttons *Premium Membership* and *Two-step Login*; the second group includes, among others, *Import Items* and *Bitwarden Web Vault*. Even though the buttons in these two groups look the same, they present distinct behaviors. When users click a button from the first group, Bitwarden warns them that it will redirect them to its web page and asks for their permission. However, in the second group, Bitwarden redirects to its web page without asking users for their permisson. This inconsistency goes against two of the "Golden Rules" of Interface Design as stated by Shneiderman et al. [21]: **Strive for consistency**, stating that actions sequences should be consistent; and **Keep users in control**, stating that some users desire the sense that they are in control. Moreover, it is known that inconsistencies in interfaces can hinder the user experience and users' mental models [4, 21].

To rectify this problem all the buttons from the second group were expanded with a prompt asking for users' permission to redirect them.

5 Evaluation

The work presented in this paper is undergoing but some preliminary results are available. In this section, we present those results and we succinctly describe the plan to evaluate the work developed.

5.1 Preliminary Results

Regarding the feedback form for the icon (see Section 4.2), we performed a preliminary evaluation with 25 participants. The goal is to identify which icon users perceive as the most adequate to signal the formal verified features. The feedback shows that the preferred icons are icons B and D (from Figure 1(a)), with icon D in the lead and icon C as the less preferred icon.

We have also performed pilot tests with the aim of refining the testing protocol and script. An example of an improvement suggested was to reduce the number of tasks. When users performed the tasks we also noticed that they did not explore the interface or clicked on the formally verified icon; after asking them the reason for this, one replied "*I was focused on the tasks*". As a result, in the next round of tests we will begin the session by going through the tutorial for all users (see Section 4.3). Another preliminary result we found was that, even though one of the users stated knowing what formal verification is, they were not able to identify how it was used in PassCert. This may be due to the lack of user interaction with the new help tools. When asked to explain what they understood by formal verification, the user stated "*Something that guarantees security*", so even though the user did not understand the concept fully, they associated the concept with security.

5.2 Further User Studies

To evaluate the success of the solution proposed, we plan to perform user studies to determine: the usability of the solution and if the best practices implemented were successful; if the problem identified by Pearman et al. [16] regarding users' lack of information about how PMs work was solved; and the impact of formal verification on the adoption of PMs.

The user studies will be divided into 4 parts. First participants will fill a "Pre-Task Questionnaire", with information about past experience with PMs and demographics. Secondly, we will provide a quick rundown of PMs. Thirdly we plan to go through a set of tasks and in between each one we will ask them to fill a related "Task Questionnaire". When participants finish they will be asked to fill a "Final Questionnaire". Before ending the session, further feedback from users will be collected. To evaluate the users' perception of formal verification in the PM we will include questions about it in the questionnaires mentioned above. These will use a Likert scale [6, 8] and the answers to the SUS on the "Final Questionaire" will be aggregated to reach a usability score from 0 to 100.

We will also register user interaction with the implemented features (e.g. if the user clicks on the formal verification icon and spends time in that screen).

6 Conclusion and Next Steps

The advantages of using PMs are undeniable. As such it is important to make users trust and want to use them. In this paper, we reviewed usability challenges

of PMs and proposed the use of known usability best practices and techniques to extend and improve Bitwarden. We have also identified usability problems in Bitwarden and described several extensions already implemented to overcome these. Even though this is a work in progress, we already carried out pilot studies to gather preliminary results regarding icons choice and usability. These pilots also helped to refine the testing protocol and task script from user feedback.

Regarding future work, the next immediate step is to perform the planned user studies, from which we expect to learn more about users understanding of formal verification and PMs. We also plan to perform longitudinal studies to determine whether the proposed usability improvements and the use of formal verification can increase the adoption of PMs.

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