Self-Managed Tool Tables in a Student Managed Makerspace
6th International Symposium on Academic Makerspaces

ISAM 2022 Paper No.: 77

Marvin Breuch[1]
[1]Student Project House, Swiss Federal Institute of Technology Zurich; marvin.breuch@sph.ethz.ch

Abstract

Supervisors of academic makerspaces are often struggling with the problem of limited financial resources. A major cost driver especially in smaller Makerspaces is the staffing [1]. Hence, the value of a self-managed 24/7 hand tool system to extend the accessibility of tools in an academic makerspace, that does not require all day supervision, is evaluated. Various solutions for different requirements are presented that are then differentiated by the complexity and costs of implementation. The possible pros and cons of each solution are further evaluated. Moreover, the solution used in the Student Project House at ETH Zürich is presented and evaluated. Based on user interviews, reports of missing or broken tools and collected usage data, the system is reviewed and important points in the user experience are pointed out. A method and applicable rules for such tool tables in student managed makerspaces are lastly deducted from the collected data.

Introduction

The demand for tool usage in a makerspace is usually high. Oftentimes the financial constraints do not allow for an all-day supervision of the tool shop by staff members. When an openly accessible workshop area is available this demand for hand tool usage can be spread from the supervised usage times to the space opening hours. To do so without the demand of the staff members always being around, a self-managed solution must be implemented.

Requirements and possible Solutions

Previous experience showed that a major requirement for the implementation of such a self-managed system is the availability of an open workspace which is designed in such a way that worktables can be placed. Another requirement for the implementation is a dedicated area in which the tools can be stored. The tools must be locked away to ensure that only eligible users can access them and a control system for self-management can be installed. Adding to this, a process for the reporting of missing tools must be developed. Such process must be low barrier, easy to use and fail safe. Lastly, it can be beneficial to show that a missing tool was already reported to the makerspace management. In the following, solutions to the requirement are presented in further detail and are evaluated.

A. *Tool Storage*

Most importantly the tools need to be secured in some way or another. Simple implementation could use a locked tool cabinet, a cabinet with toolboxes inside that is locked, smart controlled tool cabinets with electronic locks as they are sold by multiple suppliers, or others. At ETH Zurich a implementation using servo-controlled locks in custom designed tool tables, as shown in Fig. 1, has been chosen, as this method is space saving and the integration into the existing machine control system was easy to perform. It showed that a system to check for the tool storage to be correctly closed is a beneficial addition that is worth the extra price.

Fig. 1 Worktable with drawers containing tools

B. *Eligibility Check*

It is important that only users who are eligible to use the tools can get access to them. To check this, different methods can be applied which are strongly dependent on the tool storage situation. In case of number locks on doors or toolboxes the codes can be periodically changed while only eligible users are informed about the new combination. In case locks with keys are used the situation could either be solved by a big number of keys or by the usage of a key safe. There are multiple commercially available solutions on the market. The simplest and cheapest solution would be a key safe with a number lock. Again, a rotation of the combination would ensure only current eligible users have access. A more costly option would be an electronic key safe. These machines provide a complete user management system and multiple forms of identification are available (PIN, batch, Password, QR Code, etc.). Examples of such products are shown in Fig. 2. The big advantage of such a system is that it can also be used for logging. If an existing machine control system is available, it is worth discussing with the supplier if lock solutions are available so that the eligibility of the user can be checked with such system.

Fig. 2 Example of simple and complex key safes [2][3]

C. *Logging Usage*

A vital factor for keeping the costs low is a log for the usage of the tools. Using this log, the makerspace management can contact a user regarding a reported lost or broken tool. By such abilities the users are aware that the tools must be used with the highest care and that damages must be reported. Additionally, this feature can be a valuable asset in the evaluation of the makerspace performance. The simplest way of solving this requirement is a paper list. However, such a list requires high discipline of the users as the act of self-logging requires additional effort from the user side. Further, a user might be tempted to remove their entry or the complete list in case of damage. When an electronic key safe is used, the logging can usually be performed with such system. Similarly, an existing machine control system with the ability for locks can be used for data logging.

D. *Completeness Check*

For the system to be completely self-managed users must be able to report a missing or damaged tool. This task comes with two challenges. On the one hand the user must be able to identify a missing tool quickly and on the other hand the process of reporting must be easy and clear.

The first challenge must be solved in the context of the tool storage situation. If a solution with fixed spots for each tool was chosen, foam inserts or markings around the tools can be used. These solutions are both widely applied in makerspaces around the world. An example of foam inserts can be seen in Fig. 3. For non-fixed tool position, a list would be a cheap solution. However, this is more complicated for the user to control. Clear communication of the tool checks and possible consequences resulted in a high discipline and thoroughness from the user side.

For the second challenge, again, solutions could be as simple as a paper list in which anomalies are written down containing a name, date, and time. Going one-step further, a point of contact could be noted for the users. This could be a staff member that can be found working on a different project in the space or an email address. Lastly, online tools such as google forms, typeform, etc. provide a lot of functionality. Such tools can create a hands-off approach and even allow the users to upload pictures of missing tools. The communication of such tools can be done either directly on the website of the makerspace or using QR codes directly on the tool storage. Generally, a key feature is user friendliness. Only a system that is easy to use and might even implement some way of gamification, motivates the users to be precise with their checks.

Fig. 3 Tool inserts using foam cutouts

E. *Tool Labeling*

Users might be tempted to exchange a missing or broken tool when the same tools that are used in the self-managed tool storage are also used in the supervised area of the makerspace. A simple solution to this problem is to label each tool with its proper location. As this can be helpful for the general operation of the makerspace, it is recommended also when not implementing a self-managed tool storage. An example is shown in Fig. 4.

Fig. 4 Tools marked with their proper location

This can be done using several methods. A simple option would be to use colored tape and a color code for the individual positions. If available, printable shrink tube can be used. This is a very easy to adapt option that can be quickly implemented and adjusted at a later point. The screwdriver in the shown picture is labeled with such shrink tube. Another option is the use of a laser engraver or cutter. Wooden tools like the hammer shown in the picture can be directly engraved. For metal tools one must check the material of the tool and the capabilities of the laser machine. When a fiber laser is available direct engraving is possible. For simpler CO2 laser machines metal marking tapes can be facilitated. Such tapes might seem expensive at first glance, but only small amounts are needed to label a tool. This method was used to mark the pliers shown in Fig. 4.

F. *Prevention of double reporting*

A system that informs the user about previous missing tool reports is recommended to reduce the number of incoming reports. This can be realized by having specific markers that are stored in the place of the missing tool if a special location for each tool is assigned as shown in Fig. 5. In realizations where this is not the case, a simple note can be added to the toolbox.

Fig. 5 A colored insert indicated that the tool was already reported missing

Implementation

In the following, the system as used in the Student Project House at the Swiss Federal Institute of Technology Zurich is explained. The implementation is following the steps discussed before. The key feature of this system is the self-management aspect of it. This means that users that log in to one of the toolboxes are responsible for the tools themselves. A first installation of such system was done in 2017.

The underlying process for the usage which is controlled by the machine control system has not changed drastically from the first iteration to the current version. Only minor improvements have been added and will be explained further. The detailed process is shown in Fig. 6. The machine control system consists of a graphical user interface and individual control units that control power to the machines [4]. The system is using the student ID card which contains an RFID chip as identification. Students can only log in to the system after they received the general safety training. As the tool storage is electronically controlled it was added to the same system from the first version onwards.

If a user wants to use a toolbox, the electronic system checks in the database if the user already underwent the safety instructions and is not in dept. The system will unlock the tool storage if the user is therefore applicable for tool usage.

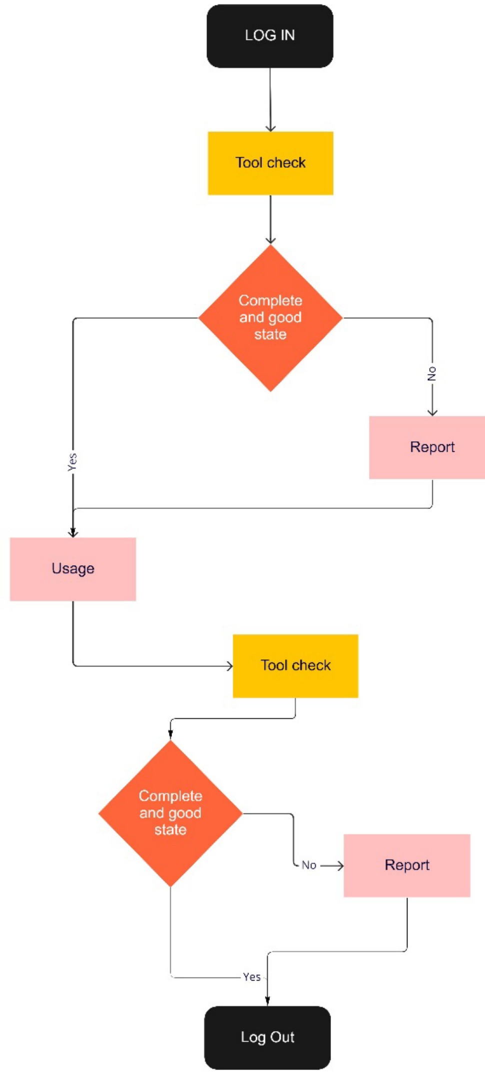


Fig. 6 Tool usage process

The first iteration is shown in Fig. 7. The tools were placed in plastic containers which were stored in a locked cabinet. The cabinet was controlled using solenoid locks and the machine control system. This ensured that only eligible users had access to the tools and logging was implemented from the beginning. As solenoid locks require high currents when activating, the controls were equipped with a complex analog electronic circuit. Since the cabinet did not provide any work area, the size of the containers was chosen to ensure that it is easy to carry the individual containers to a work bench. Foam inserts were already installed in the first version as shown in Fig. 3. This was the result of experiences made with tool storage in the supervised workshop area. In the previous usage of the makerspace, it became obvious that tools without a fixed and clearly marked position are hard to track and to check for completeness. The first iteration of foam insets was manufactured using the laser cutter in the tool shop of the makerspace.

Fig. 7 First iteration of the self-managed tool system at the Student Project House

Currently the tools are stored in custom tool tables as shown in Fig**.** 1. The tables contain five drawers, each labeled with the type of tools in them, which are controlled using servo locks. These locks have the advantage of requiring only low voltages and currents. Additionally, the locks include a sensing pin which provides information if the locks are closed properly.

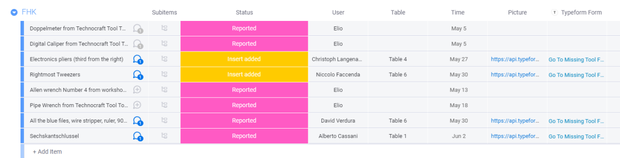
After logging in the first task of the user is to check the toolbox for completeness and good tool state. If yes, the user is free to use the tools. In case something is missing or broken the user informs the staff. In the past, this was done using a contact e-mail address noted in the plastic containers. The e-mail was received and processed by a staff member. This meant that the toolbox was checked to verify the information handed over by the users. In case the report was correct, a comparison between the reporting time and log-in time is performed. In case there is only a small duration between the two, the staff member contacts the previous user of the toolbox, as this person is thus responsible. In case the previous users cannot provide information regarding the whereabouts of the tool, the staff member creates a bill covering the costs of the tool.

As the discussions with the users showed that only a small number of users are checking and reporting tools and efforts were undergone to improve the reporting process. Feedback by the users showed that the act of writing the e-mail was received as being very cumbersome to the users. It was therefore decided to simplify the reporting for the current version by using a digital form which is communicated using a QR code that is placed on the table. According to further evaluations and discussions with users, the usage of QR codes felt more modern and simpler. It was decided to use typeform for the data collection as it was already used in other areas. The user is guided through the process in which the name, e-mail address and number of the affected toolbox are collected. Additionally, a picture of the missing tool can be taken directly and uploaded using the user's smartphone. The process ensures that all important information is handed over to the staff.

By adding an integration with Monday.com, which is used as a task board manager for the makerspace, a task is automatically created and assigned to a staff member. An example of the created task board is shown in Fig. 8.

All of this is done in the background and the user reporting something as missing can continue using the equipment.

Often when a user was confronted with the fact that a tool went missing during their usage time the response was that the user was not the one taking the tool. Nevertheless, all users were very understanding and accepted to pay for the missing tools. Over the time between 2017 and 2022 approximately a total of 10 tools had to be replaced due to being lost. Broken tools have proven to be a more difficult to manage situation. The question that needs to be asked for every report is "could a user see this by just quickly looking at the tool?". There were several reports of users reporting breaking a tool themselves. In case a user breaks a tool by accident and not by being grossly negligent the Student Project House pays for the damage. Still, some broken tools with an unknown causer had to be covered by the Student Project House.



FHK	Subitems	Status	User	Table	Time	Picture	Typeform Form
Doppelmeter from Technocraft Tool T...		Reported	Elio		May 5		
Digital Caliper from Technocraft Tool T...		Reported	Elio		May 5		
Electronics pliers (third from the right)		Insert added	Christoph Langena...	Table 4	May 27	https://api.typefor...	Go To Missing Tool F...
Rightmost Tweezers		Insert added	Niccolo Faccenda	Table 6	May 30	https://api.typefor...	Go To Missing Tool F...
Allen wrench Number 4 from worksho...		Reported	Elio		May 13		
Pipe Wrench from Technocraft Tool To...		Reported	Elio		May 18		
All the blue files, wire stripper, ruler, 90...		Reported	David Verdura	Table 6	May 30	https://api.typefor...	Go To Missing Tool F...
Sechskantschlussel		Reported	Alberto Cassani	Table 1	Jun 2	https://api.typefor...	Go To Missing Tool F...
+ Add Item							

Fig. 8 Example of the reports

A further improvement was the introduction of plastic inserts to indicate a previous report. This indicates that the tool was already reported missing, and no further actions are required by the next user. From here on the process is again identical to the one of the first iteration.

Usage Evaluation

Three methods were selected to evaluate the usage of the self-managed tool storage in the Student Project House. First, the tracking data was anonymized and evaluated. Secondly, reports of missing or broken tools were assessed and lastly a digital user survey was performed.

To begin the data extracted from the tracking is analyzed. The data shown in Fig. 9 shows the number of summed up logins for a variety of tools in the Makerspace between the 1st of January 2022 and the 17th of July 2022. This time period describes a total of 197 days. The data was obtained using the machine control system. Currently the Student Project House owns a total of 48 FDM 3D printers, 8 Studio Tables, 4 DLP Printers and 6 Woodworking machines. It is shown that the usage of the Studio Tools is developing to be the second most used tool in the Makerspace although their limited number.

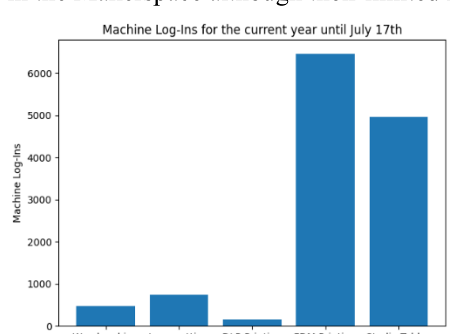


Fig. 9 Total usage number for different machines between the beginning of the year and the 17th of July

During the day, high activity at the available workstation can be observed. This can also be proven by the data shown in Fig. 10. In this plot the accumulated log-ins for the same time period are shown over the daytime of logging in. It can be observed that there is a significant peak at 4PM. This can be explained by the start of the supervised opening times of the Makerspace in which the tables are also heavily used by the users. The supervised times end at 7:30PM. Nevertheless, it can be shown that high usage starts at 8AM. When comparing the total numbers of the usage outside of the supervised times and during the supervised working hours one can observe that approximately 57% of the usage is created outside of supervised times. This data shows that the self-managed tool table reached the purpose of providing additional possibilities for manufacturing during off times.

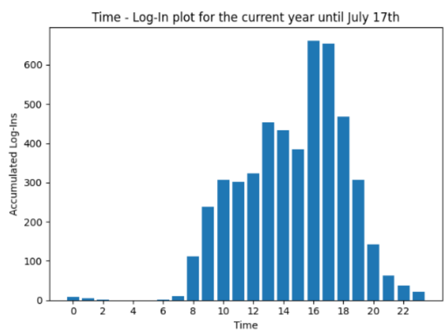


Fig. 10 Plot showing the accumulated log in times

Furthermore, the number of reports of missing or broken tools were analyzed. The starting point for the analysis was again the 1st of January 2022. The period needs to split into two as starting on the 11th of May the reporting system was switched from e-mail to the described solution using a QR code and an online form. Until the 11th of May, during a time period of 130 days, a total of eleven reports have been collected for a total of eight individual missing tools. Between the 12th of May and the 17th of July, a time period of 66 days, a total of 45 reports have been collected that indicated 16 individual instances of missing tools. It was observed that the reporting rate was drastically increased. Therefore, the beforehand described system to indicate already reported tools was implemented and integrated in the daily tasks of the makerspace staff. Importantly in the period between the 1st of January and the 17th of May only a total of 3 tools had to be replaced due to breakage and none due to being stolen.

Adding to the basic data shown above, a user survey was performed. The survey applied the structure shown in Fig. 11. The goal of the survey was to gain a further understanding of usability and possible improvements to the provided system. The survey contained rating questions using a rating system ranging from 1 (worst) to 10 (best), yes/no questions and open questions. At the beginning, general questions regarding the quality of the offer were asked, followed by a block of questions regarding the process of reporting broken or missing tools. In case the user never performed a report the concerning questions are skipped. At the end, the user had the chance to give feedback on likes and improvements to the installed system. A total of 70 users have filled out the survey. However, two users reported to never use the tables and have therefore been directly forwarded to the end of the survey.

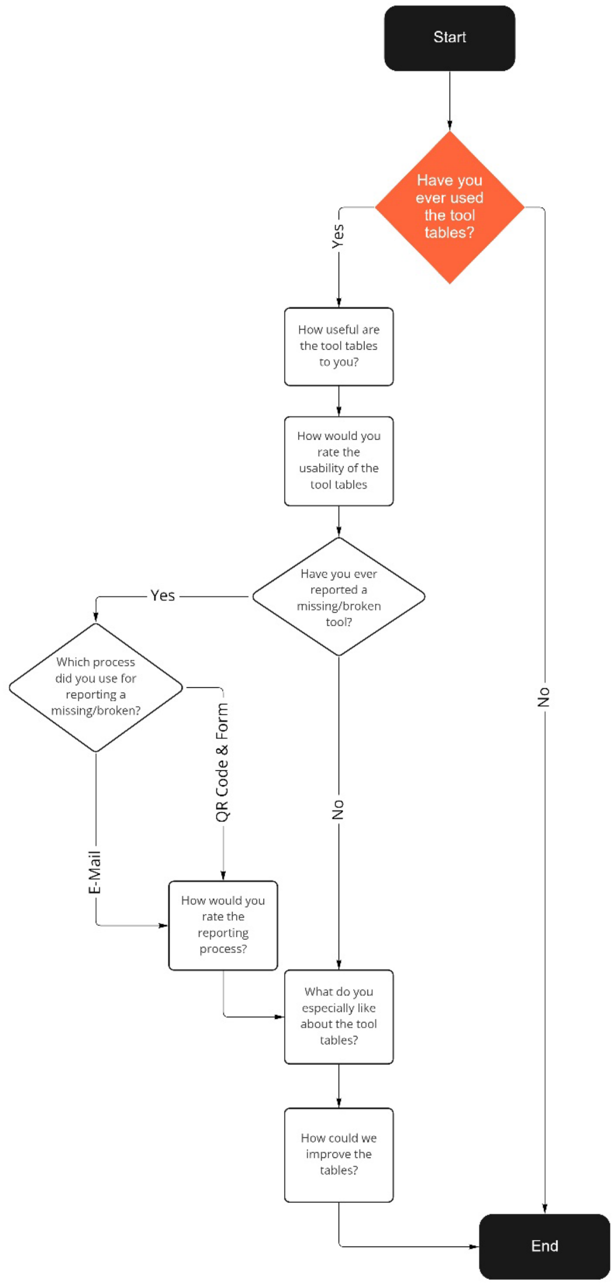


Fig. 11 User survey structure

As shown in Fig. 12 the users find the studio tables to be very useful. The average rating of the responses for this question is 9.0 supporting the supposition that was made from the usage numbers. Combining this with the results extracted from the tracking data, the overall success of a system that provides tools outside of the regular opening times can be proven.

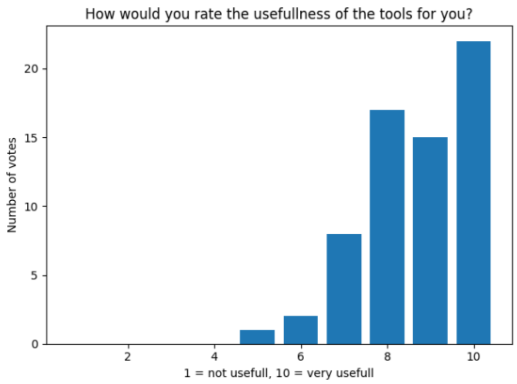


Fig. 12 User survey results for the question of how useful the tools are to the user

Similarly, Fig. 13 shows the responses for the question regarding the usability of the described system. Again, an average of 9.0 was reached, showing a high satisfaction rate. The different iteration steps showed success in making the system more user friendly.

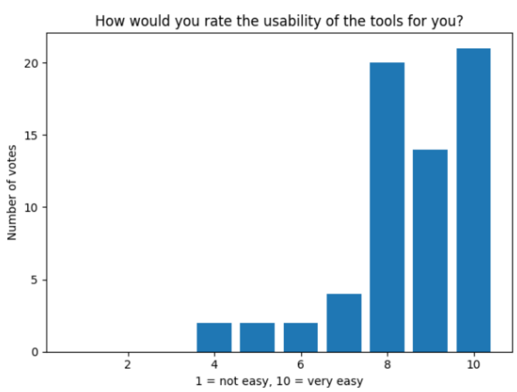


Fig. 13 User survey results on the usability of the tables

The first open question following in the survey was formed in a "I like" format. A total of 53 responses have been collected. 21 of the users pointed out that they like the organization of the studio tools. It was pointed out that the foam organization system and the easy to find tools are easy to use. Additionally, having a dedicated point for the general tool storage helps a lot in easily finding the tool a user is searching for. To continue, 21 of the questioned users mentioned the tool selection as a like. The high tool quality was also mentioned by seven out of the participants. Further, 22 of the responses referred to the accessibility of the tool outside of the supervised opening times to be of high value to them. Again, combining this with the data presented in Fig. 10 the importance of the systems are shown as it is extending the possible time for working in the Makerspace. Although not being part of the presented method, ten users highlighted that the big work surface and the power outlets at the workstations are of good quality and size. These are important features to consider when setting up a similar infrastructure. Adding to this, a big wish from the user side is a vise at the worktables so that workpieces can be fixed.. Issues with the reliability of the sensing installed in the locking mechanism were a problem in the system installed at Student Project House. Ten users commented on such previous problems even though the issues were resolved more than a month before the survey was published.

Discussion & Outlook

The implemented solution at the Student Project House offers a variety of learnings. It was shown that the importance of the self-managed tool storage may not be underestimated. The usage of the tool tables proved to be split by more than half over the unsupervised and the supervised working hours. The user feedback indicated that the organizational tools are well received. Nevertheless, the system has two major flaws which will be discussed in detail.

1. *Broken tools*
   Not all cases of broken tools can be immediately seen. It is hard to hold a user responsible for a smaller damage that can be easily overseen during the short check at the beginning of the usage period. The tools can however be chosen in a way that tool breakage is limited by either type of tool or by selecting a higher quality tool.

2. *Intentionally stolen tools at the beginning of usage*
   One big issue with the presented system is the fact that it can be easily manipulated so that the previous user would need to pay for a tool. This would be the case when a user logs in and immediately reports a missing tool while stealing it themselves. With the current system such behavior cannot be prevented.

A further minor problem with the presented systems is the expected user behavior as the system is trusting on the users to check all the tools. With the current 5 drawers per table this can be a tedious task. However, there are several possible solutions to this problem. As the designed and installed electronics can check the status of each lock there is the chance of tracking which drawers were used. Using this the user would only need to check the completeness of the drawers they used. This would be possible by only adjusting the used software and database in the backend. A different solution would be to add a user interface to select which drawer to use. By using this in combination with the fact the used hardware is capable of opening individual lockers, the user again is only responsible for the lockers that they used. An automated system would solve this pain point of requiring the discipline of the users to check the drawers. One possible implementation could include a camera system with an ultra-wide-angle lens and a computer vision algorithm that checks the drawers after the log out. This would however be complicated to implement but very useful addition as it would also prevent the situation described in point 2.

References

[1] J. Gottbrath, I. Charnas, “Makerspace Staffing Models: A Survey” *In Proceedings of the International Symposium on Academic Makerspaces*, 2019.

[2] Screwfix Direct Ltd 2022, “Master Lock Water-Resistant Combination Lock”, 2022. [Online]. Available: https://www.screwfix.com/p/master-lock-water-resistant-combination-safe/77908. [Accessed: 24- Jul-2022].

[3] Loxtore RFID Systems AB, “RDID Key Management”, 2022. [Online]. Available: http://www.loxtore.com/tag/rfid-key-management. [Accessed: 24- Jul- 2022].

[4] M. Breuch, M. Först, “Student ID Scanner – How to log and secure machines using off the shelf Parts,” *In Proceedings of the International Symposium on Academic Makerspaces*, 2017.