Research

Project Puzzlebox

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Version 0.0, 2024-04-01: draft

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1. Microcontrollers used in the current state (Elwin)

1.1. Research

The boxes consist of four sides in use (games) which can be seen in the Attachments figures 1 through 4. One of the games (safe puzzle) seems to be unfinished upon visual inspection which also includes a lose display. The games that seem to be implement are the following:

- Safe puzzle: Figure 3
- Neotrellis puzzle: Figure 4
- Software puzzle: Figure 5
- Hardware puzzle: Figure 6

The bus cable (Figure 11) consists out of five connectors with ten lines, the main controller (as already known) is a Raspberry Pi 3B+ with an 8GB MicroSD card and a custom PCB 'head' see Figure 14. There are 4 custom PCB's with a microcontroller slot and a connector for the 10-line bus, two of those are used for the sides and one is unused and also empty see Figure 9. Of all the custom PCB's only one seems to be professional made from a factory see Figure 10, the others seem to be made at school in the lab.

- Safe puzzle PCB: Figure 8
- Software puzzle PCB: Figure 7

There is also one development board from Adafruit see Figure 12 but this one does not seem to be connected to any bus. The underside of the box has a large light sensitive sensor which is also not connected see Figure 13.

The more professional custom-made PCB has an ESP32-PICO-D4 as microcontroller see Figure 10. The other custom-made PCB's do not have any microcontroller installed but seem to be made to be used by a ESP32-PICO-KIT V4/V4.1.

1.2. Summary

There seems to be four games implemented where of only one may work because of its integrated ESP32, the other three also may work if the missing ESP32's are included but it is unclear if the 'unknown' PCB should be used in combination with the Neotrellis panel and what need to be done with the safe side to get it to work.

1.3. Conclusion

It could be quite possible that the 'unknown' PCB should be connected to the Neotrellis panel based on the data lines properties. But besides that, only the software may need to be updated in order to run on the ESP32's as soon as the 'missing' ESP32 dev kits are in stock.

But everything could be made less complex, more cost effective and power efficient by using other type of microcontrollers. The RPI could be downgraded to a RPI Zero or an ESP32 dev kit. The microcontrollers used for the sides could be replaced by a much smaller chip like the ATTiny or a Atmega32.

This can only be done if the following requirements are met:

- Dev. Board or daughterboard with spring or screw terminals
- A microcontroller with enough IO
- A microcontroller with all the required communication busses.
- It may not cost more than one day to rebuild the system.

A follow up research should reveal which microcontroller and dev. Board / daughterboard is best fitted for this project.

1.4. NOTES

The Dev kits are not available and newer types do not meet the current footprint of the custom PCB's. So it is suggested that the next group will design a pcb with another MCU on it in order to match the pin layout and make use of a smaller more efficient chip. Or they can convert the prototype PCB's to a production version with the ESP32 chip on it (if the chip it self it still available at that time) or pick another MCU in that stage anyway.

The hardware side uses a single DSP (HC166) to process the input of the switches, the software side uses two shift registers (74HC59SD) to control the LED's.

Issues

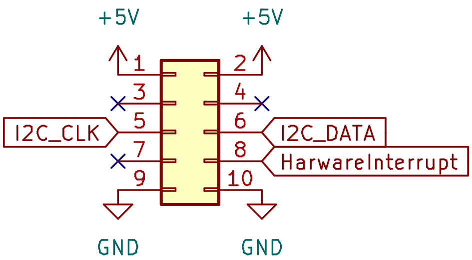
1. Button row 4, col 1 for the safe side needs to be replaced (missing a pin)
2. LED strips for the software and hardware sides only work for 50%.

1.4.1. Appendix (Loek)

The puzzle bus connector (see Figure 11) appears to have 10 conductors in total. The hardware schematics from 21-22 reveal the pinout of this bus connector, which is shown in Figure 1.

After searching through the other design documents from this year, no references to the "HarwareInterrput" line or interrupts in general were found. The puzzle source code folders also did not contain code which initialized this line as an interrupt. It is assumed this line is unusable, as it is connected but has no specified functionality.

Figure 1. Puzzle bus pinout



Source: [1]
(Connector key is next to pin 5)

2. Controllers (Loek)

To mitigate power consumption issues discovered by the 21-22 group, new controllers were chosen for this year's (23-24) run of the puzzle box project. This section compares different microcontroller options for both the main controller and controller used in puzzle modules.

2.1. Main controller

The following criteria were used to compare MCUs that are suitable candidates as main controller unit:

- Must have at least 1 I^2C peripheral (R-136).
- Must be able to connect to a standard 802.11b/g/n access point (R-137).
- Must be able to serve TCP socket connection(s) (R-138).
- Should be power efficient (R-166).
- Is available as a development kit from Farnell (R-139).

Table 1 lists the considered MCU options matching the above criteria. This list is a compilation of microcontroller offerings from the following manufacturers: Atmel, Espressif, Raspberry Pi.

Of these controllers, the Raspberry Pi RP2040 has the lowest clock speed and highest memory.

Its lower clock speed means that it will likely draw less power than the other options. It also happens to be less expensive than all other options. Due to these reasons, the RP2040 was chosen as main controller MCU. The Raspberry Pi Pico W board is utilized during development.

Note This was written while we did not know the puzzle bus specifically requires slave-addressible I^2C multi-master controllers to function properly. The RP2040 was still used, but has required implementing workarounds. Please see the handover report for more details on how this impacted the project [2].

Model	I^2C peripheral count	SRAM	Flash	Clock speed
WFI32E01PC	1	256 KB	1 MB	200 MHz
ESP8266	1	50 KB	16 MB	160 MHz
RP2040	2	264 KB	2 MB	133 MHz[1]

Table 1. Main controller MCU candidates

2.2. Puzzle module controller

The following criteria were used to compare MCUs that are suitable candidates for controlling the puzzle modules:

- Must have at least 1 I^2C peripheral (R-141).
- Should has enough I/O ports to directly control moderately complex puzzles (R-142).
- Should be power efficient (R-143).
- Is available as a development kit from Farnell (R-145).
- Has a configurable clock speed (R-144).

Table 2 lists the considered MCU options matching the above criteria. This list is a compilation of microcontroller offerings from the following manufacturers: Atmel, STMicroelectronics, Raspberry Pi.

All the MCUs listed in Table 2 support some version of a low-power mode. The RP2040 is again included and appears here because it supports clock speed configuration and has a clock gate for each peripheral [3], which may make it a feasible option with regards to power consumption. Choosing the RP2040 may also simplify the development process as only a single MCU toolchain needs to be maintained.

The Microchip PIC16F15276 is the most power efficient on this list and is the recommended MCU for puzzle modules. It supports both extreme underclocking and has a low power mode. This chip is available as the 'MICROCHIP EV35F40A' evaluation kit.

Because this year’s run of this project was carried out by a team consisting only of software students, this choice remains as a recommendation. The puzzle box hardware may still use the ESP32 development kits from the 21-22 group.

Note This was written while we did not know the puzzle bus specifically requires slave-addressible I^2C multi-master controllers to function properly. We have not verified if the PIC16F15276 supports this feature.

Model	I/O ports	I^2C peripheral count	SRAM	Flash	Clock speed
PIC16F15276	40	1	2 KB	28 KB	32 kHz – 32 MHz
STM8L152C6T6	41	1	2 KB	32 KB	38 kHz – 16 MHz
RP2040	26	2	264 KB	2 MB	10 MHz – 133 MHz

Table 2. Puzzle module controller MCU candidates

2.3. Conclusions

The main MCU that is utilized for this year's (23-24) run of this project is the Raspberry Pi RP2040 on the Raspberry Pi Pico W. The recommended MCU for new puzzle modules is the Microchip PIC16F15276. The existing puzzle modules still utilize the ESP32 development kits chosen by the 21-22 group.

3. Unit Testing Framework Research (Thomas)

3.1. Research question

Which unit testing frameworks are available and relevant to the project, keeping in mind RTOS-specific frameworks, and what features do they have?

3.2. General framework comparison

In Table 3 is a general comparison shown of multiple different frameworks. These are either a header-only testing framework, a testing framework specifically designed for embedded systems, a general-purpose C++ library, or a specialized C++ unit testing framework. The following sub-sections will give more information about each framework and their features.

Framework	Language	Lightweight	Mocking Support	Portable
CppUTest	C/C++	Yes	Yes (CppUMock)	Yes
Catch	C++	Yes	Limited	Yes
Doctest	C++	Yes	Limited	Yes
Google Test	C++	No	Yes (GMock)	Yes
Boost.Test	C	Yes	Limited	Yes

Table 3. General testing framework comparison [4, 5]

3.3. CppUTest

A C/C++ based unit testing framework, designed specifically for testing C/C++ applications on embedded systems. It can be used for testing general C/C++ code and supports TDD-style tests (Test-Driven Development). This is due to it being a header-only testing framework, and not requiring linking of external libraries.

It offers multiple different assertion macros for verifying expected behavior and supports the mocking of functions and memory leak detection. It works on most platforms, including Unix-based systems, Cygwin, and MacOS. It can be integrated with build systems like Make or CMake. The framework is also compatible with RTOS-based applications and Raspberry Pi, both require configuring the development environment to allow CppUTest to work. It supports up to the C++17 standard, after which there is experimental support for the C++20 & C++23 standards. [6]

3.4. Catch

A C++ unit testing framework designed in a straightforward and expressive manner. Just like CppUTest it is a header-only testing framework and doesn't have any external dependencies, but instead of supporting TDD-style testing, it supports BDD-style testing. Which is Behavior-Driven Development-style testing, where test cases can be written in a natural language format (Given-When-Then statements).

It offers a simplified testing syntax, and assertions look like C++ Boolean expressions. It allows the developer to organize tests into sections, providing a local (in file) way to share setup and teardown code. It also allows developers to tag tests and run tests selectively using their tags. The framework is also compatible with RTOS-based applications and can be used on a Raspberry Pi. It supports up to the C++20 standard, after which there is experimental support for the C++23 standard. [7]

3.5. Doctest

A C++ based unit testing framework, designed to be minimalistic, easy to integrate and expressive. It supports C++11/14/17/20/23 and allows for writing tests directly in production code, due to it being a single-header library.

The tests written with this framework are automatically discovered and executed without any manual registration. It has no separate compilation steps for the tests as it is header-only and is thread-safe by default. It also allows for customizable test output formats and is compatible with RTOS/Raspberry Pi. [8]

3.6. Google Test

A C++ based testing framework, following the xUnit architecture, which is used for structuring tests. It is a single-header library just like doctest; however, it does require the developer to write tests in separate test files. It has minimal external dependencies allowing it to easily integrate into projects.

It supports mocking functions and has a large variety of assertions for verifying expected behavior, including death tests. It allows the developer to run tests multiple times with different input values and the developer can set up common test environments using fixtures. Furthermore, it allows for custom assertions and test output. It is also thread-safe by default. It supports testing for RTOS/Raspberry Pi, as well as C++20 and lower. There is experimental support for C++23. [9]

3.7. Boost.Test

A C++ based unit testing framework, designed for writing, and organizing unit tests. It is compatible with C++11/14/17 and can be integrated with C++ projects running on RTOS platforms. However, even though you can use Boost.Test on the Raspberry Pi, it does not have direct Raspberry Pi-specific features.

It supports the creation of test suites, allowing the developer to group test cases into logical suites. Furthermore, it provides a wide range of assertion macros for checking test conditions and can generate test result reports in various formats (e.g. XML, human-readable). It works on most platforms, including Windows, Linux, macOS, and other Unix systems. [10, 11]

3.8. Conclusion

After going through the researched unit tests a few things can be noted for each framework. CppUTest has been designed for embedded system testing and has features for memory leak detection and mocking. However, it is supported until C++17 while the other versions for C++ are all experimental. Catch allows for easy test creation. Furthermore, it allows for test tagging meaning you are able to run tests selectively using their tags and it is supported up to C++20. Doctest allows for writing tests directly in production code, meaning a second test file is not necessary. It has an automatic test discovery function, as well as being thread safe on default and allowing customizable test output formats. Google Test uses xUnit test architecture and supports mocking functions. It has a large variety of assertions including death assertions and supports running tests multiple times with different input values. It allows custom test assertions / test output and is thread-safe by default. It also has support up to C++20. Boost.Test allows for writing and organizing unit tests and has support for C++11/14/17. It supports the creation of test suites, making test grouping possible. It has a large range of assertion macros and can generate test result reports in multiple different formats.

After going through the notable features of the different testing frameworks Google Test was chosen as the testing framework for this project. As it has a structured syntax, readability and a lot of features required for reliable testing. Including mocking tests, a large amount of assertions, multiple test with different input support, and lastly being supported in the newest non-experimental version of C++.

4. I²C (Thomas)

4.1. Research question

How can we use I²C for the puzzle module detection and communication?

4.2. Puzzle Module and Main Controller Communication

Research from project group 21/22 shows that the I²C protocol is the best option for communication between the puzzle modules and the main controller. This research section extends the previous section about which MCU is suitable for the puzzle bus, as we have found vital I²C limitations with the controller we had chosen. See the handover document for the found limitations.

4.2.1. MCUs Supporting Master Addressable as Slave

Atmega328p

The Atmega328p has multi-master support, where the MCU is addressable as a slave while being in master mode. This has been confirmed using the Arduino wire library on both the Arduino Mega and the Arduino Uno.

PIC16F15276 & ESP32

Both the PIC16F15276 [12] and the ESP32 MCUs show possibilities to be addressable as a slave while being in master mode. However, at the moment of writing this has yet to be tested.

4.2.2. Alternatives

PIC16F15276 Registers

In the case of the PIC16F15276 [12] not support master addressable as slave the following approach would most likely work. As the PIC16F15276 uses specific registers for its master receive functions, namely the RCEN register, it can be manually set to receive data from the I²C bus. However, this also has yet to be tested.

Multiple I²C Peripherals

4.2.3. ESP32 & RP2040

The ESP32 [13] [14] [15] and the RP2040 both have multiple peripherals for I²C communication, while also supporting simultaneous configuration. This allows both two I²C peripherals to be active, one being configured as a master and the other being configured as a slave. This enables the controller to send and receive data to the I²C bus without much difficulty. This does introduce increased code complexity but is a valid option if it is succesful in testing.

4.3. Puzzle Module Detection

Puzzle module detection is vital to the puzzelbox, as this allows changing the puzzles without much software or hardware configuration needed. An option will be given for the choice of main controller (RP2040); namely to scan the full I²C bus for responsive slaves. The RPI Pico SDK has an API for I²C which also supports functions create a bus scanning function. An example of this bus scan function, according to the API examples, can be found in the pseudo code below.

```
#include <stdio.h>
#include "pico/stdlib.h"
#include "hardware/i2c.h"

void bus_scan() {
    int ret;
    uint8_t rxdata;

    for (int addr = 0; addr < (1 << 7); ++addr) {
        ret = i2c_read_blocking(i2c_default, addr, &rxdata, 1, false);
        printf(ret < 0 ? "." : "@");
        printf(addr % 16 == 15 ? "\n" : "  ");
    }
    printf("Done.\n");
}
```

The bus scan function tries to read data from all possible I²C addresses, and prints a table which shows what the addresses are from found I²C slaves. This is possible due to the i2c_read_blocking function, which returns the length of the read data if the slave address is in use (in this case 1) or a number below 0 if the slave address is not in use. The puzzelbox, however, has the 'Neotrellis' puzzle which also uses I²C to function. The bus scan function would also see the 'Neotrellis' rgb matrix as a puzzle module (slave) using this implementation. This can easily be fixed using a handshake between puzzle modules and the main controller, as the 'Neotrellis' rgb matrix cannot answer this handshake and is therefor not recognized as a puzzle module.

5. Original Puzzle Box Functionality Research (Thomas)

5.1. Research question

What gameplay functionality should the original puzzle box have had?

5.2. Group 2019-2020

5.2.1. Hardware Puzzle

The hardware puzzle was to be a puzzle consisting of two parts, a puzzle using a 555-oscillator and a puzzle using a multi meter. The 555-oscillator puzzle would be used to give students an idea how they can create a typical hardware application. The multi meter puzzle would introduce students to the usage of the multi meter, while giving the bomb group the values measured using the multimeter which then correlates with 3 different potentiometers.

5.2.2. Software Puzzle

The software puzzle was to be a puzzle which introduces the student to an Arduino. The puzzle box would contain an Arduino, a few switches, and a few LEDs. The student would be able to program the Arduino by using a visual drag-and-drop programming language. This program would have to get an input value, which is given by the switches, and an output value shown on the LEDs. The idea is to get both the input and output value correspond with each other.

5.2.3. Automation Puzzle

The automation puzzle would introduce the student to a factory structure, consisting of multiple 'tubes' which contain a certain color. These colors could be mixed by the students to get the corresponding colors shown in their game manual. The tubes which contain these colors would have to follow a specific route, and are to join with other tubes, creating new colors which makes the puzzle a bit more complex. The valves to open and close the tubes are grouped to add another difficulty level to the puzzle. See Figure 15 for an example of this puzzle.

5.2.4. Safe Puzzle

The safe puzzle is a puzzle created to test the communication skills of the student. It shows a code on the puzzle box, which then needs to be given to students with the game manual, who give the students at the puzzle box the button they must click. This needs to be done 5 times before the safe opens and the last code is given to defuse the bomb if a wrong button is clicked the safe resets and they need to start over from the beginning. See Figure 21 & Figure 22.

5.3. Group 2020-2021

The automation and safe puzzle were not changed this year.

5.3.1. Hardware Puzzle

The hardware puzzle was revised this year, it would include a quiz which helps the students with solving the puzzle and has a completely different interface from the first one. The quiz questions can be found in the document "Speluitleg_puzzlebox_39-06-2021", which can be found in this project's directory. Once the students solve the quiz, they can push the button found in the puzzle, and morse code will be given to the students. The code given using morse code is one of the required codes to disarm the bomb.

5.3.2. Software Puzzle

The software puzzle was also revised this year, instead of a puzzle using a visual drag-and-drop programming language it would instead contain two columns which would need to relate to each other. One column shows digital ports, which is part of 'Digitale Techniek' and the second column contains letters corresponding with C code. This code can be found in the game manual and requires the students to communicate between each other which letter which code is. Once all cables are connected the LEDs above the puzzle will glow in binary, this needs to be deciphered into decimals to get another code to defuse the bomb. An example of this puzzle can be seen in Figure 16 & Figure 17.

5.3.3. Neotrellis Puzzle

A new puzzle was added to the box, namely a neotrellis-type puzzle. This would mainly be a puzzle requiring a lot of figuring out, as it does not correlate with any of the three directions in the Technical Computer Science curriculum. It would contain an 8x8 LED button system, where you can toggle the LEDs by clicking on a button. You complete the puzzle by getting a matching pattern with the one given in the game manual. See Figure 18, Figure 19 & Figure 20 for examples of this puzzle.

5.4. Group 2021-2022

The software, automation, safe, and neotrellis puzzles were not changed this year.

5.4.1. Hardware Puzzle

The hardware puzzle was revised again this year, removing the quiz, and making it a data flow puzzle using logic gates and circuitry. There wasn't any more information about the way to solve the puzzle. See Figure 6 for an example of this puzzle on the puzzle box.

5.5. Group 2022-2023

No puzzles were changed this year.

5.6. Conclusion

The puzzles have gone through a lot of changes and designs, but in the end the following puzzles will be used from project group 2019-2020:

- Automation puzzle
- Safe puzzle

The following puzzles will be used from project group 2020-2021:

- Software puzzle
- Neotrellis puzzle

And the following puzzle will be used from project group 2021-2022:

- Hardware puzzle

The way these puzzles are solved has been summarized in this research document, but the most complete versions of how to solve these puzzles are given in the group's respective design document.

6. Research of hardware designs of previous groups (21-22 and 22-23) (Lars)

This part of the research looks at the hardware designs of the previous groups that did this project. These are compared with each other and finally the points of interest are given that the software must meet in order to work with this hardware.

6.1. Design of 21-22 group

This group has developed a puzzle box with a puzzle on all sides. Each puzzle has to answer a question from the different directions in this study. So, think software, hardware and an automation puzzle. The 21-22 group designed and started the realisation of a physical puzzle box. The status of the puzzle box is a carved wooden box containing one mainboard hat for the Raspberry PI 3B+ (chosen for its availability), one puzzle based on the ESP32-PICO-D4 system on chip (SOC) and three puzzle prototypes based on the ESP32-PICO-KIT (D4 development kit). The puzzle boards are mounted on the sidewalls of the wooden box and are game technically largely functional. Behind this chosen hardware is not a thoughtful choice but was chosen mainly due to availability and because these components have been used by students before.

The four puzzles have game-playing software, but the puzzles have not yet been play-tested. All puzzles run on the same state machine, the communication module for I2C communication between the puzzles is integrated but not yet fully implemented. So, communication is possible but not processed in the state machine other than resetting the game and reading the state. The I2C module for the mainboard has also been worked out in a C++ application for the Raspberry PI 3B+.

To communicate via a network between the puzzle box and the bomb, a hub is used. Next to the connection between the devices in the local network, the hub will also connect to the internet for time synchronization and external configuration. The hub will also act as a webserver for the configuration of the boxes and bombs and, as a network manager for the communication between the devices. The hub makes also use of a Raspberry Pi 3B. The raspberry pi for the main hub will be combined with a wireless USB dongle due to the need for multiple wireless radios. The USB dongle used for this project has not been defined, any dongle supporting the 802.11x standard will qualify.

6.2. Design of 22-23 group

What did the group from 22-23 develop as a hardware design?

At the start of their project, the 22-23 group has been busy re-structuring the puzzle box developed by 21-22. The basis of 21-22 was not well structured, there were low requirements and specifications and little research available. As a result, this group (21-22) did have time to realise their design. However, the end result of this was a half-working puzzle box with no coherent hardware. As a result, the 22-23 group chose not to implement hardware but first structured the project properly with requirements and then went on to create a thoughtful design.

The new design consists of a mainboard connected to the puzzle box via a puzzle bus (consisting of: 5V, 3.3V and I2C). The idea of the puzzle box is that it is developed modular way so that puzzles can easily be removed and inserted. Therefore, one standard interface (puzzle bus) is designed to which every puzzle can be connected. Each puzzle therefore also needs its own microcontroller to control the logic. So, the choice of microcontroller of both the puzzles and the mainboard has not yet been made by this group. However, this group did give a number of points that the microcontroller must meet in order to work with the hardware design:

- Operationeel op een voedingsspanning van 3.3V of 5V
- Ondersteuning van I2C
- Voldoende I/O voor aansturing puzzels
- Sleep mode (aanbevolen)

The main architecture (Figure 2) includes the USB-C adapters, puzzle boxes, bombs, puzzle box hub and the computer. These components are powered by batteries and communicate with each other via Wifi meshing (is not yet working). Through the puzzle box hub, a computer can be used to configure and start the system. So, the puzzle box itself consists of several sides on which a puzzle can be played. With the outcomes of all these puzzles, the entire box can be solved and opened.

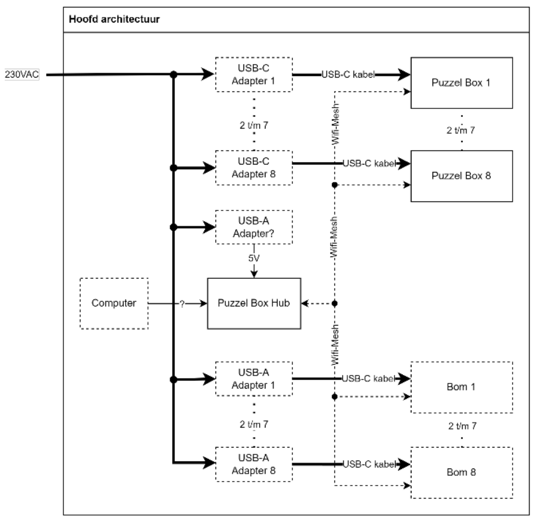


Figure 2. Main architecture

6.3. What are the differences between the designs of the 21-22 and 22-23 groups?

Overall, the designs of the two groups are not far apart. The topology is similar to each other. What does differ is that the 21-22 group chose available ESP32 modules for the separate puzzles, while the 22-23 group left the choice of microcontrollers open. This is because this group consisted only of hardware students and the choice of microcontrollers also affects the software to be written. The other difference is that the 21-22 group only tells how they realise the design without indicating which design choices they made for this and what other options there were. The 22-23 group did do this and described it in the design document.

6.4. What to consider when developing software

The hardware group (22-23), in addition to the recommendations in the requirements package, has provided enough information to work with as a software group.

It was recommended by last year's group that software students pick up the following steps:

1. Choose suitable microcontrollers
2. Understand the operation of wifi mesh + set up the web page
3. Create software design for puzzles and mainboard
4. Integrate the software into the puzzle box

With all these recommendations combined, the following points should be kept in mind when developing the software:

- Software should be written separately for each puzzle as a module.

  As described, each puzzle is a separate module so that these puzzles can be adapted later when required. So, provide a good architecture in which puzzles can be modified, added or removed without changing the whole structure of the software.

- Make sure the software works with the given hardware designs of groups 21-22 and 22-23. Elwin's research showed that the main board consists of a Raspberry Pi. The puzzles are run on an ESP32, so the software for this should consist of a language compatible with these devices, for example C++ or Python.
- The individual modules communicate via the I2C communication protocol. So, make sure it is clear that the Raspberry Pi is the master and the ESP32s serve as slaves. The addresses of the separate ESP32s should be unique and properly configured for this purpose.
- The software must be flexible to allow modules to be modified later
- If the puzzles need to be modified later, the software must be written in a way that can be understood. Think of good documentation and comments accompanying the code. In addition, use programming languages from the standard curriculum of the program. So that other students can continue working with them later.
- The 22-23 has not yet been able to calculate the power supply of the puzzles, so this should be taken into account when implementing the systems. Think of a certain function or power-saving mode that turns off certain puzzles/modules when not in use.
- Provide test documents
- Provide well-documented software, think comments in the code and a handover document. The intention is that after this project, the software will be almost ready for use, groups should also be able to understand the software at a later stage. Also, for students with lesser software knowledge.

Appendix A: Attachments

Figure 3. Safe side

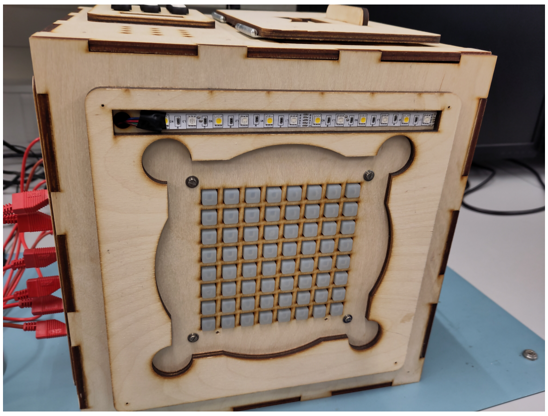


Figure 4. Neotrellis side

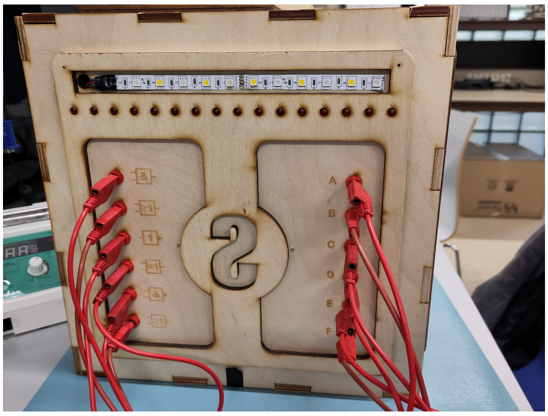


Figure 5. Software side

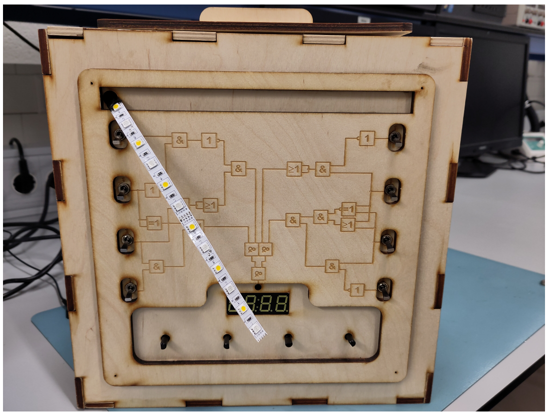


Figure 6. Hardware side

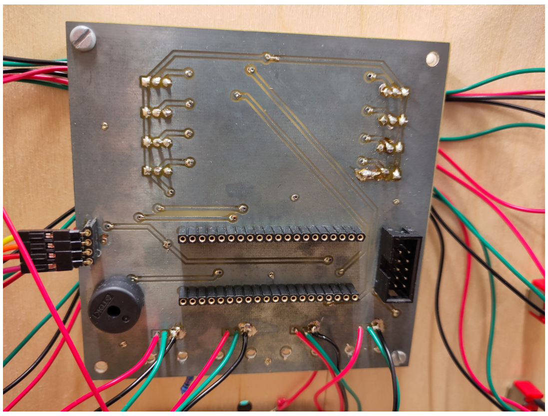


Figure 7. Software side PCB

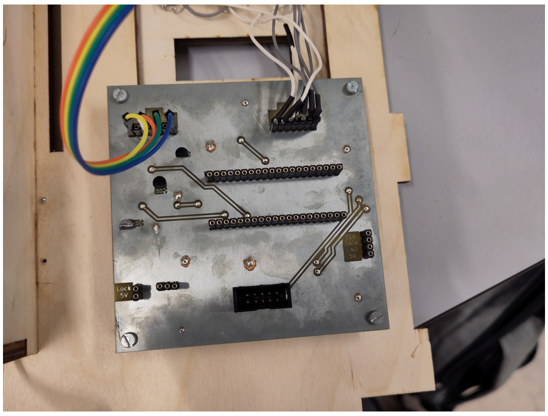


Figure 8. Safe side PCB

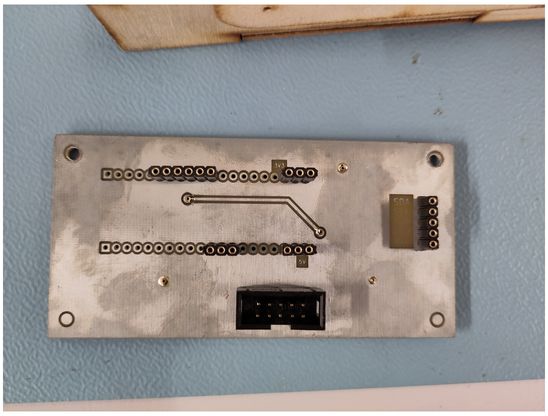


Figure 9. Unknown PCB

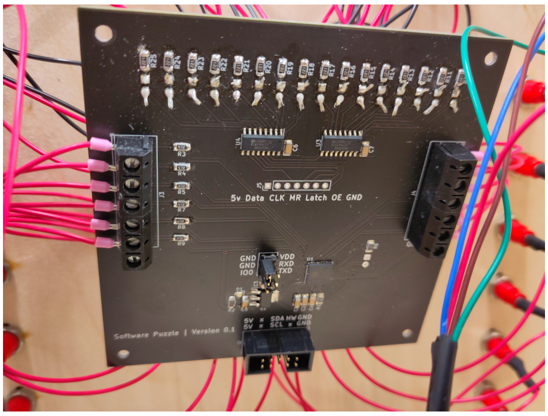


Figure 10. Hardware side PCB

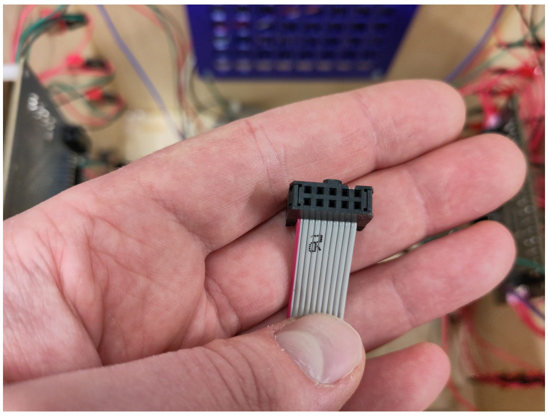


Figure 11. Bus cable

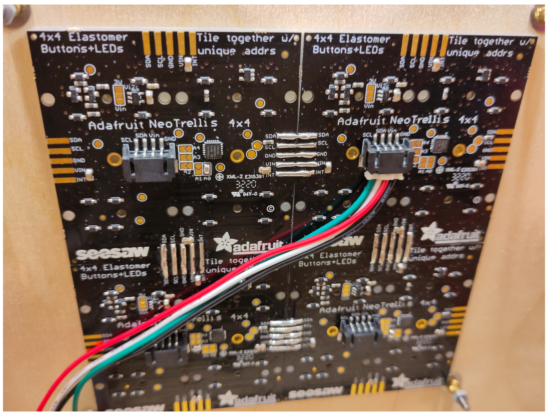


Figure 12. Neotrellis side PCB

Figure 13. Light sensor

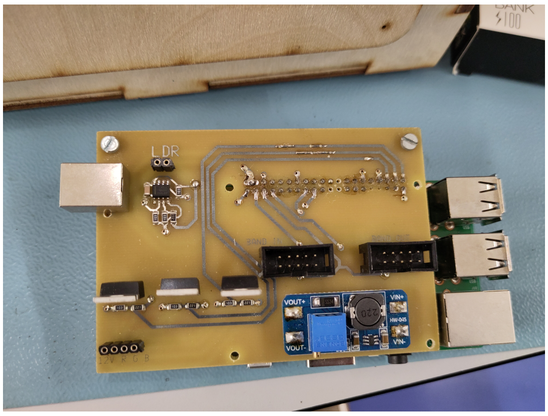


Figure 14. RPI PCB (Head)

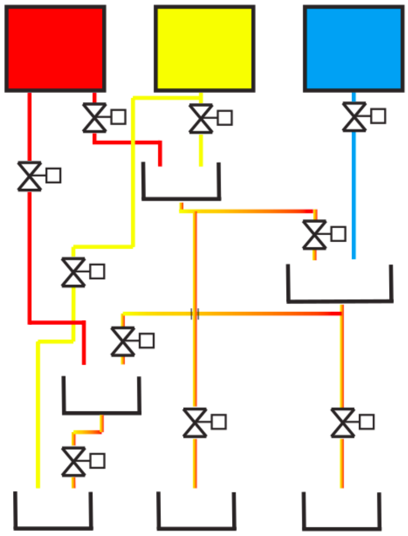


Figure 15. Automation puzzle example

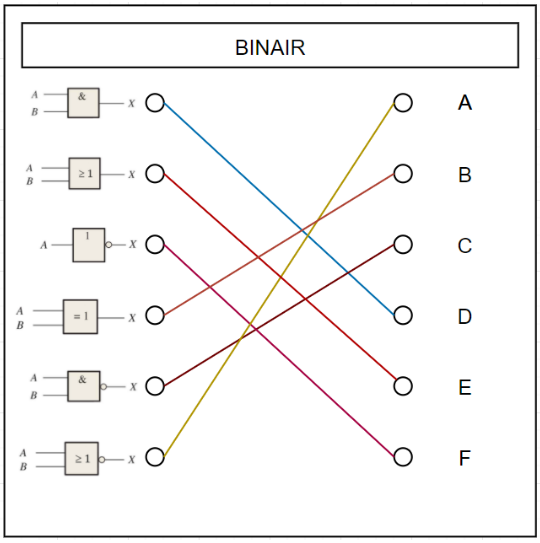


Figure 16. Software puzzle box example

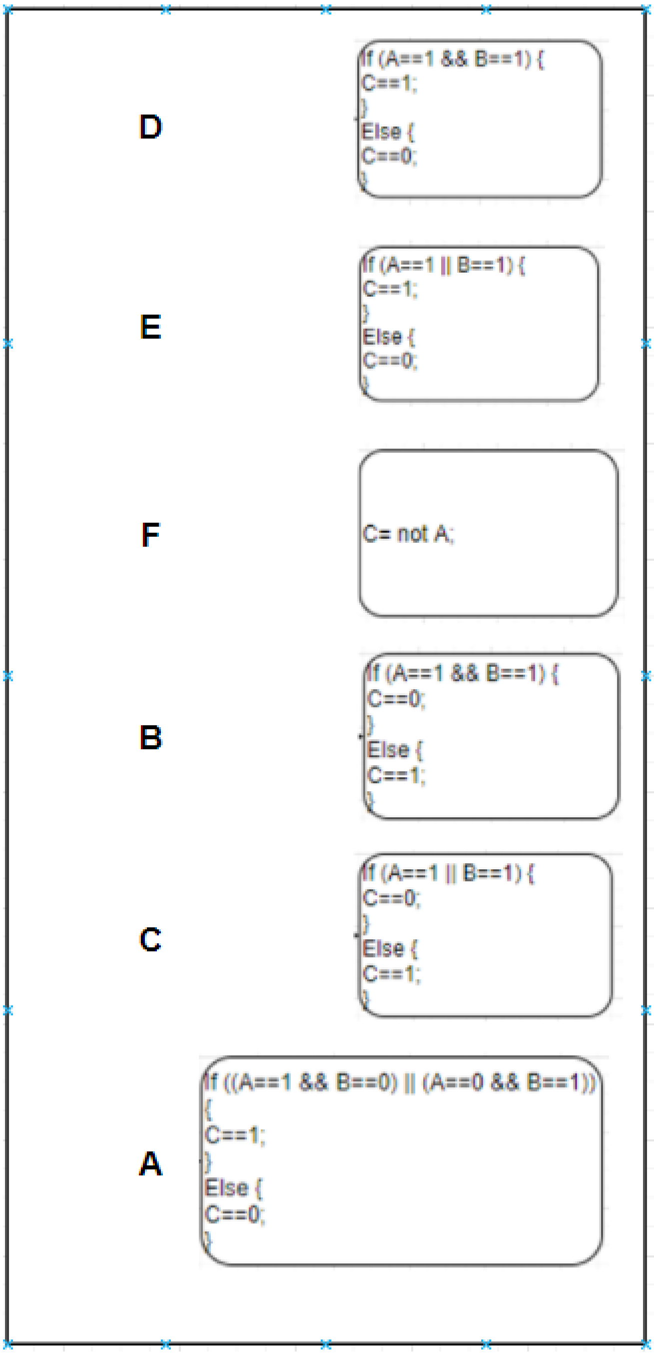


Figure 17. Software puzzle game manual example

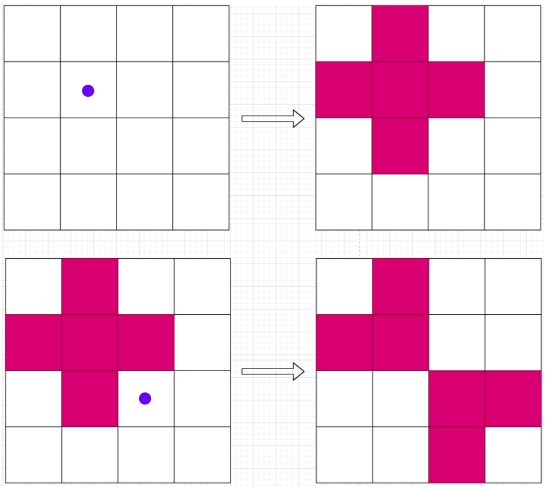


Figure 18. Neotrellis puzzle toggle example

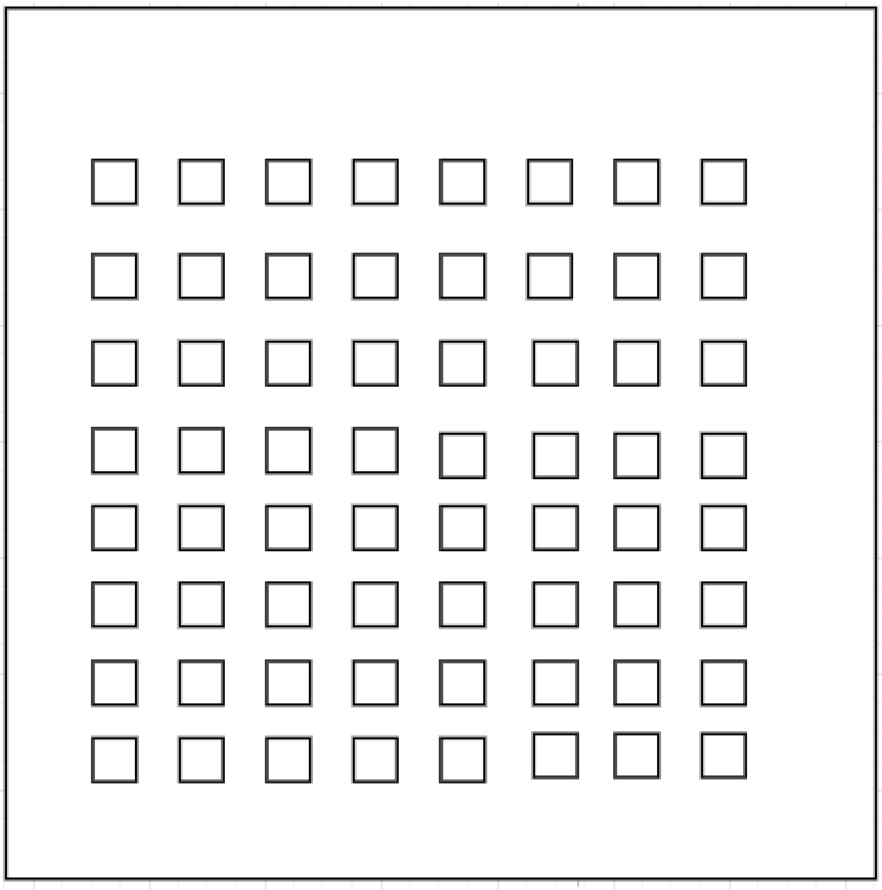


Figure 19. Neotrellis puzzle 8x8 example

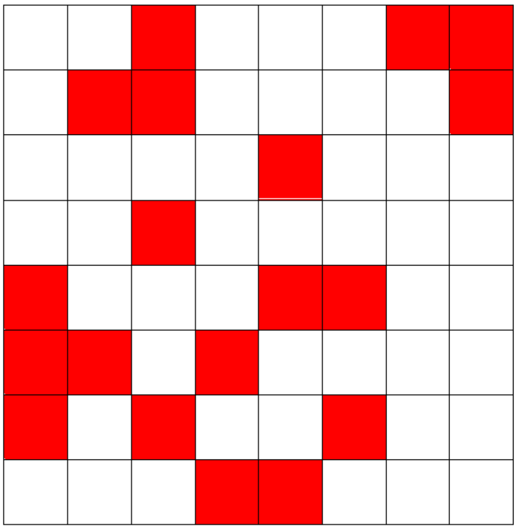


Figure 20. Neotrellis pattern example

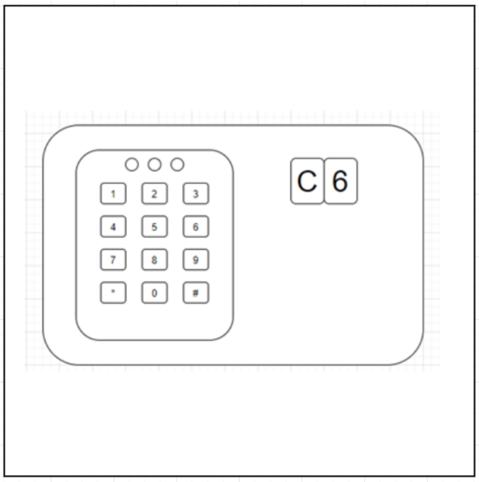


Figure 21. Safe puzzle schematic example

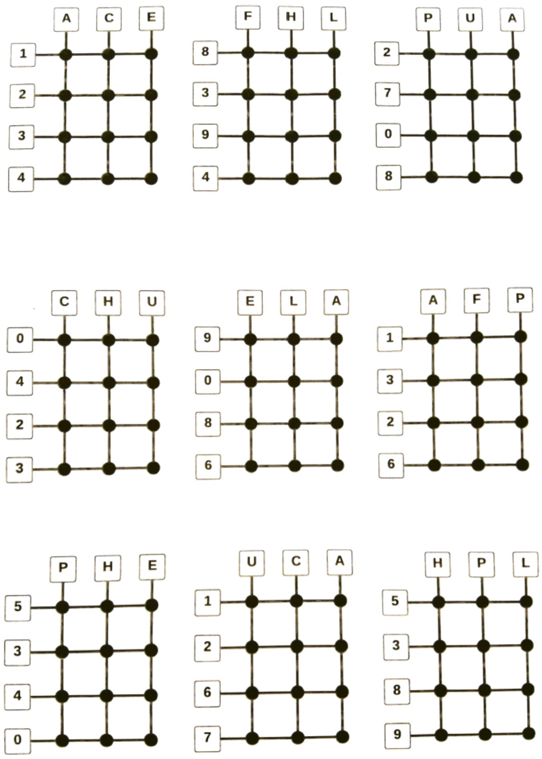


Figure 22. Safe puzzle combinations given in the manual

Appendix B: References

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Appendix C: Glossary

RPI
Raspberry Pi

Main board
The main board is the PCB on the bottom of the puzzle box, this communicates with the puzzles and the bomb

Puzzle box hub
The puzzle box hub communicates with the puzzle box and the bomb, as well as helps with configuring them

SID
Security identifiers

game operator
Person who organizes a puzzle box play session

[1] Adjusting the clock speed for the main controller is not necessary, even though the RP2040 supports clock speed configuration (see Table 2)