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# Reengineering in STEAM: Rehabilitation of a C3Tec Permanent Exhibition

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***Abstract*—The Creole Center for Science and Technology of the Caribbean (C3Tec), located in the urban center of Caguas, Puerto Rico, it is a unique interactive teaching alternative in the Caribbean. However, some of its permanent exhibits require substantial updates and repairs. That is why a collaborative agreement was established between the Center and the Ana G. Méndez University (UAGM) with the objective of making these improvements by applying reengineering. This paper presents the rehabilitation of the most important exhibit which demonstrate the feasibility of the agreement.**

***Keywords*—Reengineering, STEAM, Interative Learning, Sustainable, Environmentally Aware.**

## I. INTRODUCTION

IN recent years, reengineering is presented as a key strategy to address the challenges facing the educational system around the world. This strategy aims to adapt education to the expectations and needs of students, teachers and other individuals involved in the educational process [1]. In addition, reengineering puts into practice the knowledge acquired at the university through innovation by searching solutions to real problems [2]. This education with interactive learning significantly enhances educational outcomes by fostering a dynamic environment where students actively participate and engage, thus boosting their interest and motivation. Also this improves their communication and collaboration skills, learning how to express their ideas clearly and work effectively in teams [3].

C3Tec is dedicated to exploring, discovering and enjoying the wonders of modern technology through interactive exhibitions, theater, conference rooms and special events, with the objective of promoting environmental, ecological, urban and global awareness of the community, especially young people. [4]. It is visited by more than 100,000 people annually since its opening in 2015. However, several of the permanent exhibits needs to be updated due to technological advances, requiring personnel with knowledge in electronics, computer systems and programming.

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This work responds to a collaborative agreement between C3Tec and the electrical and computer engineering department at UAGM, with the main objectives of applying of reengineering in the university learning process, strengthening competencies in electronics and programming languages, and making updates and improvements to the permanent exhibits. The organization of the article is as follows: Section II describes the permanent exhibition worked on. Section III shows the proposed updates and section IV discusses the experimental results. Finally, section V presents conclusions and future work.

## II. ECOLOGICAL HOUSE EXHIBITION

### A. System Description

This exhibition (see Fig. 1) consists of build a physical house at a scale level, by placing its main components such as the floor, walls, doors, windows, and roof by selecting different available options. A screen will show in 2D all the selected movements and indicate errors when assembling the complete structure. Through a score awarded, the efficiency of the assembled ecological structure could be verified. This game is effective at any age and allows to relate actions with visualization in real time based on the principle of action and effect [5], [6].

The exhibition has been out of service since 2017 because the system is analog and outdated. However, the program still fully functional with the computer's keyboard.

### B. Problem Details

The current (non-functional) electronic circuit uses analog technology with homemade antennas and wireless communication based on Radio Frequency Identification Technology (RFID) that require replacement (see Fig. 2(a)). The exhibition visual component was created in *Unity* software [7] like a game (see Fig. 2(b)). This program consists of receiving signals through antennas and translating them as input to the computer to press a key. Table I shows the exhibition parts


Figure 1. Ecological House Exhibition.


(a) (b)

Figure 2. (a) Non-Functional Electronic Circuit. (b) Visual Component.

mapping. Characters 1, 6, u, r, a, f, and q are used for reset one part of the house.

## III. Proposed Updates

As the visual component program still fully functional with the computer's keyboard, the UAGM team propose the integration of an Arduino microcontroller that will emulate a computer keyboard, so when an antenna reads a tag depending on the Unique Identifier (UID) a corresponding defined key is pressed.

Table I
Exhibition Parts Mapping

| Item | Character |
|---|---|
| Roofs | 2 to 5 |
| Front Wall | 7, 8 |
| Back Wall | w, e |
| Sidewall1 | t, y |
| Sidewall2 | i, o |
| Landscape | g, h, j |
| Entrance | s, d |

### A. Electronic Component Update

The proposed electronic circuit is based on RFID technology. A microcontroller (Arduino Leonardo) will generate and send the signals required by the software using the USB port. Then the visual component can be used for visualization purposes.

*1) RFID Antennas and Microcontroller Connection :* The connection between the antennas and the Arduino is quite simple. The signals SCK (Serial Clock), MOSI (Master out Slave In), and MISO (Master In Slave Out) can all be connected in parallel because these are standard SPI bus lines and are controlled by the Master device (the Arduino Leonardo). These signals are taken from the ICSP (In-Circuit Serial Programming) pins. The RST (Reset) can be connected in parallel as show the schematic presented in the Fig. 3.

The 3.3V is supplied by an external source due to the Arduino could not supply all the power needed to operate the 7 antennas. The schematic does not include the 7 antenna connections but the only signal that will be different in all antennas will be the SS (Slave Select).

In reader 1 (antenna) the SS1 signal comes from digital pin 13 in the Arduino. All SS signals will be connected to a different digital pin in the Arduino. Each SS connection can be changed by modifying the code and changing the pin definition.

*2) PCB Multiplexer Design :* A PCB was designed (see Fig. 4) to divide the SCK, MOSI, MISO, RST GND, and 3.3V in a parallel connection, and the SS signals are independently connected. The red lines are the copper traces for each signal, and the purple panels are ground plane to reduce noise within the connections.

### B. Software Implementation

The developed code was designed for an Arduino project that uses multiple MFRC522 readers to detect RFID cards, read their UIDs and, based on those UIDs, simulate keystrokes on the computer on the exhibition. This way, when the user uses some of the RFID cards we provided, the application on the monitor on screen can be used. To emulate a keystroke, the UIDs that the user provides with the RFIDs cards from the antennas needs to be identified. Then, the following three libraries are required: i) *SPI.h* to establish communication between the Arduino Leonardo and the MFRC522; ii) *MFRC522.h* to facilitate writing/reading and authentication; iii) *keyboard.h* for keyboard emulation [8].

Algorithm 1 to 4 presents a simple step-by-step code description. In general, the program runs in a continuous loop, verifying each RFID reader to detect some cards used for the code. When one of these cards is detected and its UID is read, it is compared with a list of known UIDs from our cards. If a match is found, a predetermined character is emulated as a keystroke, which could be used to control the application on the computer presented in the exhibition. This process allows

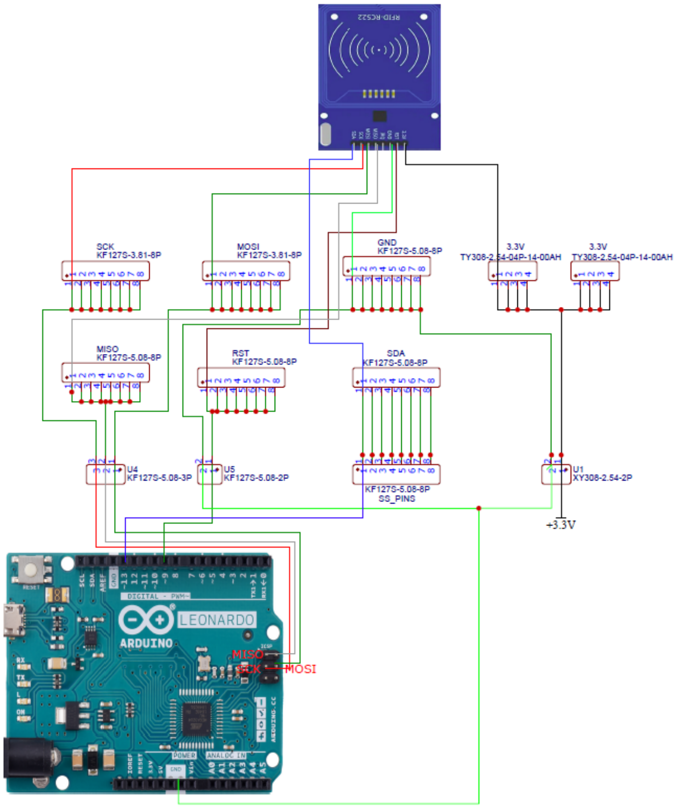


Figure 3. Arduino, Antennas, and PCB Connection Schematic.

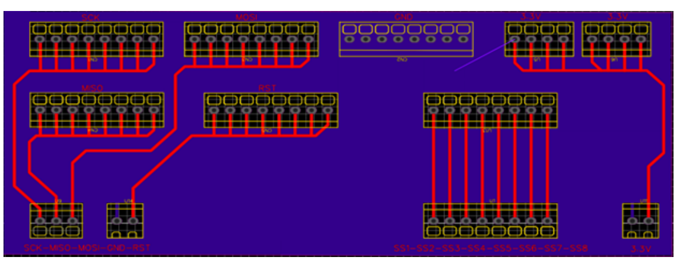

Figure 4. PCB Interconnection Circuit.

the system to automatically respond to different RFID cards presented, making the project suitable for accessing the desired program.

The designed system also incorporates a verification and error handling process that guarantees reliability in the detection and processing of RFID cards. Each card is scanned to verify that the UID matches a predefined and authorized list, ensuring that only valid interactions are processed. If an error is detected, such as an unrecognized UID or problems in SPI communication, the system records these incidents and omits the action corresponding to one of the RFIDs already registered, maintaining the integrity of the operational process. The adaptability and configurability of the system is

**Algorithm 1** CASAS_7_readers

```
Defines the reset and selection pins for the 7 RFID readers.
Create an array with the selection pins for each reader.
Defines a structure to map UIDs to keys.
procedure PRESSKEY(key)
    Press the key corresponding to the UID read.
    Wait a short period.
    Release all pressed keys.
end procedure
Initialize multiple arrays of RFID reader instances for each area of the house.
procedure SETUP
    Starts serial communication.
    Wait until serial communication is ready to be used.
    Starts SPI interface for the peripherals.
    for RFID reader from 0 to a number of readers do
        Initialize RFID reader (selected and reset pins).
        Prints the reader and firmware version numbers in the serial communication.
    end for
    Start the keyboard emulator.
end procedure
Call procedure LOOP
```

**Algorithm 2** Function to proceed continuously

```
procedure LOOP
    for RFID reader from 0 to a number of readers do
        if RFID == NEW then
            NUMBER = Called dump_byte_array.
            Print the reader and card UID number.
            for each set of UID-key mappings do
                if NUMBER == UID in mapping set then
                    Called pressKey (NUMBER).
                    break.
                end if
            end for
        end if
    end for
end procedure
```

**Algorithm 3** Comparison of Unique Card Identifiers (UID)

```
procedure MATCHUID(uid, uidSize, desiredUID)
    if uidSize is not equal to 4 then
        return false
    end if
    for i from 0 to uidSize - 1 do
        if uid[i] is not equal to desiredUID[i] then
            return false
        end if
    end for
    return true
end procedure
```

**Algorithm 4** Print byte array as hexadecimal values

```
procedure DUMP_BYTE_ARRAY(buffer, bufferSize)
    for i from 0 to bufferSize - 1 do
        if buffer[i] is less than 16 (0x10 in hex) then
            Print 0 and buffer[i] (in hex)
        else
            Print " " and buffer[i] (in hex)
        end if
    end for
end procedure
```

Table II
EXHIBITION PARTS MAPPING

| House Item | Score |
|---|---|
| Single-Pane Window | 1 |
| Doble-Pane Window | 2 |
| Non-Insulated Front Wall | 0 |
| Insulated Front Wall | 1 |
| Non-Sustainable Wood Side Wall | -1 |
| Sustainable Wood Side Wall | 1 |
| Dark Roof | -1 |
| Light Celling | 1 |
| Green Roof | 2 |
| Solar Panels Roof | 2 |
| **Floor in Front of the House** | **Score** |
| Hard Pavement | -1 |
| Grass Lawn | 1 |
| Trees | 1 |
| Native Plants | 2 |

highlighted by its ability to adjust to different hardware configurations or exposure requirements, allowing easy expansion or modification of the number of readers and card types supported through minimal changes to the source code.

## IV. RESULTS AND DISCUSSIONS

Table II shows the possible scores for the ecological House based on user selection. The maximum possible score is 8 points. The exhibition under test is presented in Fig. 5.

### A. Testing Results

The exhibition test were performed on January 16th, 2024. 8 high school students from different institutions use the exhibition following the available instructions. Fig. 6 to Fig. 10 summarize the test results. As presented, 50% of the students got 2 points when selecting the kind of double-pane windows. One student chose a not sustainable (hard pavement) which produces heat around the house when exposed to the sun radiation.

For the wall selection, only one student did not get points because his selection was non sustainable wood. Finaly the same student makes other mistake for roof selection, the rest of them understood the sustainable energy concepts very well.

Fig. 10 shows the total scores. The average was 78%. These results demonstrated that the circuit work perfectly and the students learned the concepts of sustainable energy through construction of the ecological house.

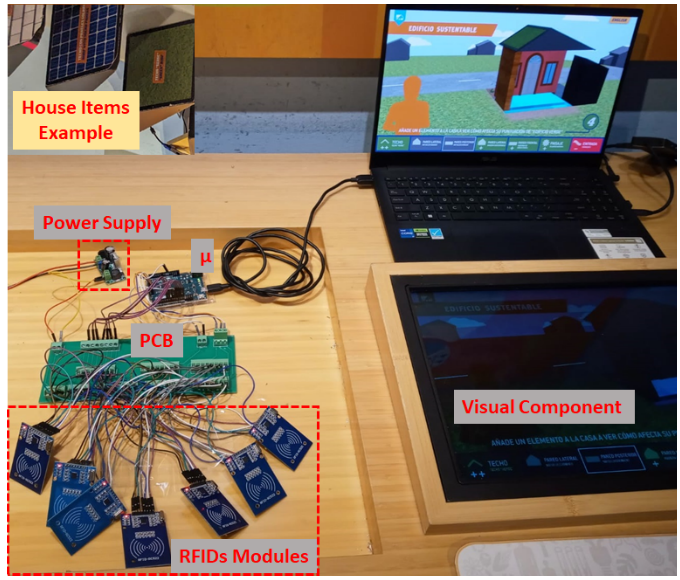


Figure 5. Exhibition Under Test.

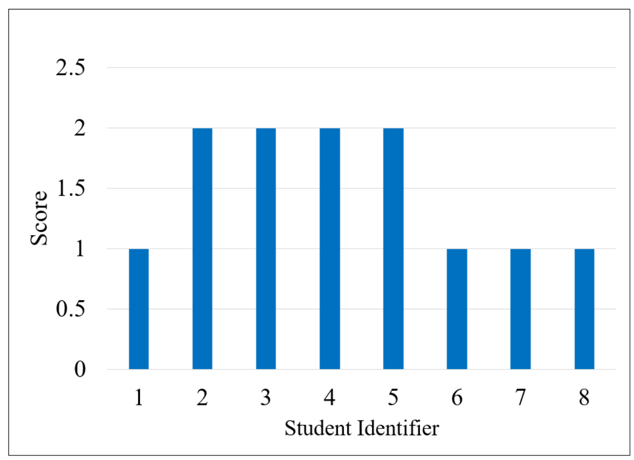


Figure 6. Windows Selection.

### B. Circuit Power Consumption

Table III shows the circuit power consumption (~1.6W) in operation mode. This was a 84% reduction compared to the previous circuit (~10W). The main factors contributing the power savings were: i) the RFID modules and the Arduino Leonardo are manufactured with low power mosfet technology instead the the old transistor logic technology (TTL); ii) the new antenna's power consumption for the new circuit is less than 0.1W instead the the older antennas (~3W) constructed manually using high impedance coils; iii) the new power supply is a Buck DC-DC converter with an efficiency greater than 90%.

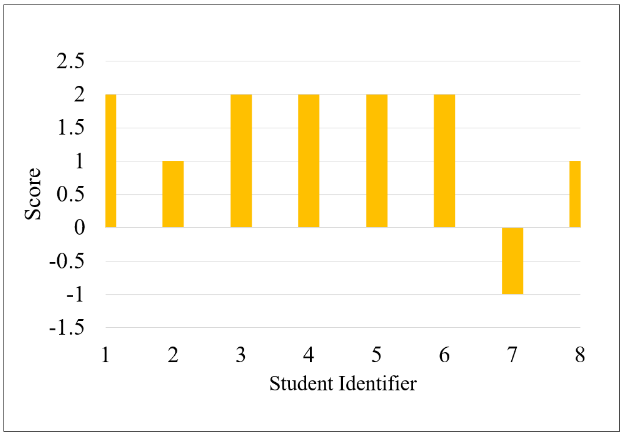


Figure 7. Floor in Front of the House.

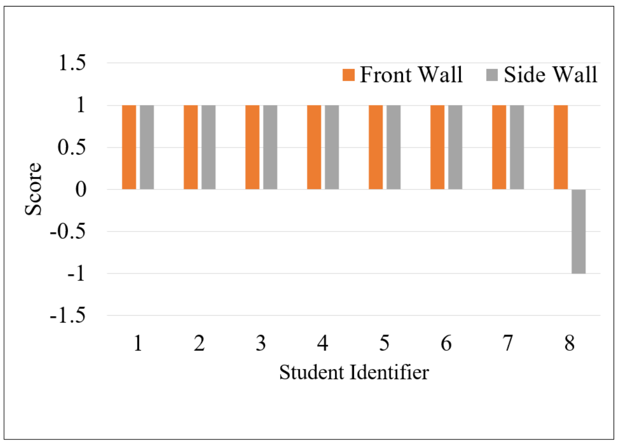


Figure 8. Wall Selection.

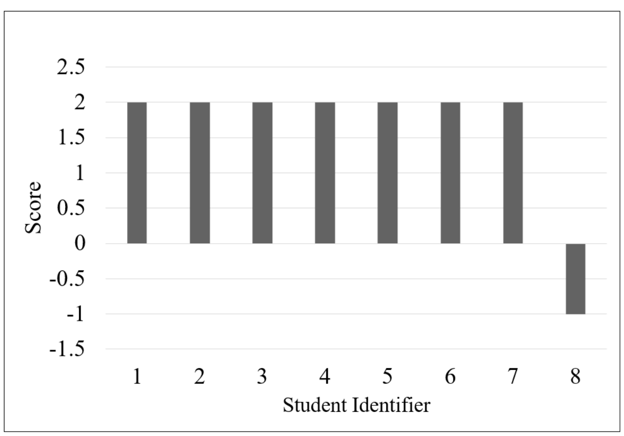


Figure 9. Roof Selection.

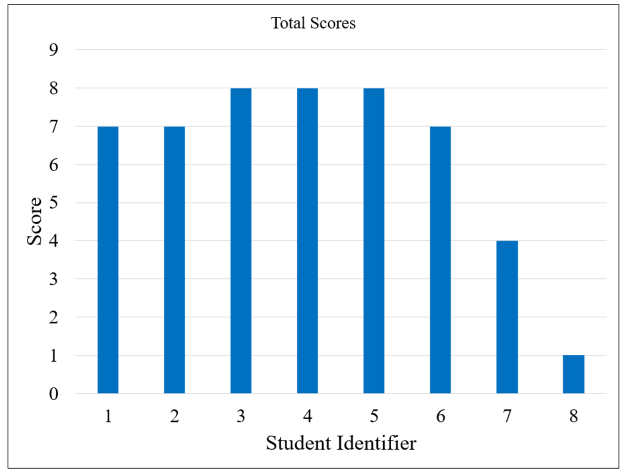


Figure 10. Total Scores.

Table III
CIRCUIT POWER CONSUMPTION

| Component | Voltage (V) | Current (mA) | Power (W) |
|---|---|---|---|
| 7 RFID readers | 3.3 | 182 | 0.6 |
| Arduino Leonardo | 7 | 140 | 1 |

Also, this new version can be powered in two ways: using a 110VAC power wall outlet or an inexpensive small battery to make it portable. In the experiments a 12V/5AH battery was used and the operation time was 1.5 days of autonomy.

### C. Performance Analysis

The measured algorithm execution time in Arduino Leonardo after processing the complete code was 0.25 seconds. In comparison with the old circuit latency of 1 second, the reduction was 75%. The graphic user interface delay after a house hardware component is located above the RFID receiver and the signal is triggered is approximately 1.0 second.

### D. Component Cost

Table IV shows the component cost of the project (∼240 usd) without the computer. It is inexpensive and demonstrates economic feasibility compared to buying a new exhibition for thousands of dollars.

### E. Educational Impact and Sustainability

Through this project, important objectives were achieved. People who visit the center learn renewable energy concepts and the importance of building houses with the best energy-efficient materials including green areas and nature. The Creole Center recovers this exhibition with a minimal budget and in a sustainable way because recycled components from the previous exhibition were used, reducing electronic pollution and maximizing the use of materials.

The UAGM students obtained real engineering design experience and used reengineering to propose this long-term

Table IV
COMPONENT COST

| Component | Cost (usd) |
|---|---|
| RFID readers (x7) | 25 |
| Hook up Dupont wires | 15 |
| 2.54mm pitch pin headers (x10) | 40 |
| UMLIFE DC to DC step down Buck converter | 5 |
| UMLIFE DC to DC jack socket (x2) | 5 |
| 110VAC/5VDC 1A power adapter | 10 |
| Arduino Leonardo | 30 |
| PCB Manufacturing | 70 |
| Duracell battery 12V 7AH | 40 |

sustainable solution. The implemented design can be easily upgraded in both software and hardware, ensuring it can operate smoothly in the future. Also, easy long-term maintenance of the rehabilitated exhibition was guaranteed, because the Windows 11 operating system can be adaptable to new releases and updates of Microsoft operating systems. In addition, the use of Arduino technology and RFID sensors in the electronic component is well supported collaborative global system (open source) and its replacement components are easily interchangeable.

## V. CONCLUSIONS

C3Tec provides a space where the community learns science and technology in an intuitive and interactive way. The reengineering strategies applied were the current evaluation of the exhibits state, the redesign and innovation phase, the implementation phase, and finally the testing phase and analyzing the results. In addition, learning is promoted by applying the concept of didactic sequences. These sequences are a set of interrelated and chained learning activities, aimed at the development of a final product [9].

Also, the engineering students who participated in this project, applied the concepts learned throughout their careers in solving a real problem while reinforcing important skills such as research, development, implementation, and validation of proposed designs. Improvements in the circuit's power consumption and response time demonstrate that students applied the concepts learned in their profession.

The impact of using reengineering in this and future exhibitions will be significant with respect to the efficiency and effectiveness of C3Tec's operation; this will undoubtedly improve the satisfaction of users who visit the facilities of this technological center. In addition, the modular implemented circuit allows future improvements, and easy and cheaper replacements if required. All Algorithms, PCB's designs and manuals were step by step documented and uploaded to the Creole Center database.


## VI. ACKNOWLEDGMENTS

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