EG2300 Engineering Design II – Systems

Term 2 Group Project Assignment: Design and Implementation of a Head Count and Seat Availability System for City St. George's Main Campus Library

Group 1:

Anna Zarubina : Sensor System logisim, Error Detection and Correction - sensor, Research Analysis, Report Writing, Analysis, figures generation.
Dhriti Singh: Arithmetic counting unit Logisims, BCD Logisim, Error Handling - Adder Subtractor, Report Editing (inc. Technical Implementation, system design)
Aidar Mekeshev: Counter Logisim, Counter Technical Implementation, Energy Analysis
Dias Slimov: Counter Logisim, Counter Technical Implementation

Research and Feasibility Analysis

The objective of this project is to design a system that would display the number of people on the library floor and display real time seat availability. The project should also be scailable to other library floors. The focus floor of the system was selected as floor 4, due to its lower number of seats (112) figure 1, lower popularity (less crowded), figure 2, and no group study areas.

	Individual study places	Group study places	Fixed workstation PCs	Total seating capacity per floor
Level 2	18	43	49	109
Level 3	13	94	56	163
Level 4	112		12	124
Level 5	215		12	227
Level 6	284		15	299
TOTAL	642	137	143	922

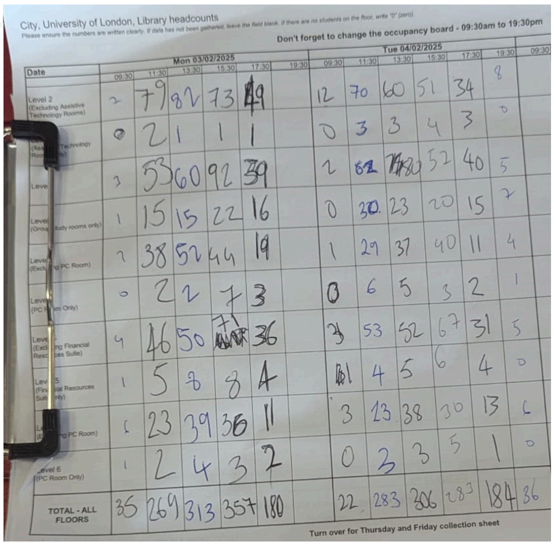

Figure 1- Seat Capacity of Library *Figure 2-Occupancy of the Library*

Library management team provided with figures 1 and 2.

The free seat occupancy is calculated by subtracting the number of people on the library floor minus the total seats available. This assumes that a person that entered a floor, occupied a seat. However, not everyone entering the floor takes a study place, some come to borrow a book. Since City StGeorges University Has digitised the library, fewer users enter to for book borrowing this increases a chance of entering the library and occupying a seat, e.g. for revision. There are about 40 staff that are present in the library, and most use a different staircase, and their own areas. This implies that the staff presence doesn't affect the floor capacity.

To track the entries/exits of the library, 4 laser sensors are placed in a straight line along the library entrance hallway, as depicted in figure 3. Using only 2 sensors is not sufficient to accurately determine entry or exit, the system would not be robust however using 6 sensors would increase the complexity of the system as well as its cost and energy consumption, without improving accuracy. The placement of the sensor on the left wall is done because floor 3 has a toilet on the right side. The sensors were placed at 130cm height, figure 3. This is to ensure detection across different body types, avoid leg triggered double activation and to make it more inclusive e.g. would count people on the wheelchair. Ceiling mounting of sensors was discontinued due to difference in the ceiling heights and detection issues, as only people walking on the centre would be detected. The option of detecting the entrance or exit by door movement detection was not considered as some people may slam the door causing it to oscillate afterwards, causing unnecessary activations when no person is passing.

The selected setup error handles the simultaneous sensor trigger, and also takes into account entries/exits from people who changed their mind halfway and did not complete a full entry/exit.

The door width was measured as 90 cm, but it opens with an 80 cm radius, figure 3. The sensors are placed 84cm from the door frame to prevent false triggers, and damage by the door. The average human width with a backpack was measured as 60cm. Hence sensors need to be placed further than 60cm from one another, to prevent 2 sensors being simultaneously triggered by the same person. The total span of the sensors is 445 cm, this ensures that miscounts are minimised and multiple sensors are not blocked by one person.

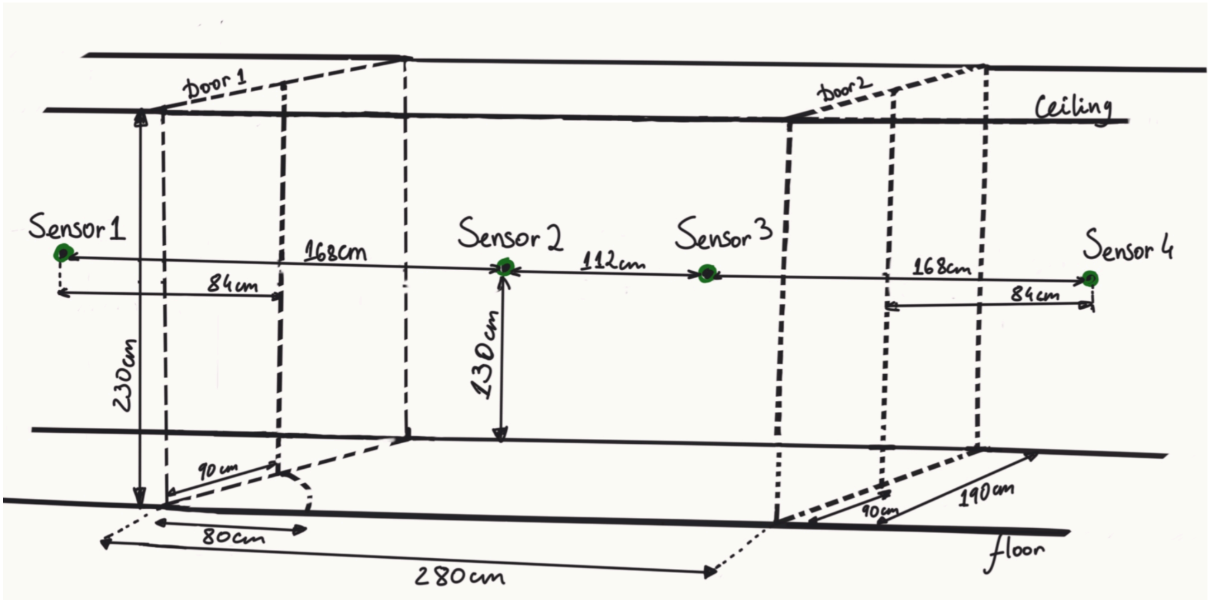

Figure 3- Sensor Layout and Measurements

The placement of the main processing unit should be in a safe place in the library reception or staff office where it can be reset by staff daily. The connection to the reset button and the main unit will be done wirelessly.

Sensor Choice

To minimise the false detections rate especially in the bright sunlight a laser proximity sensor was chosen. Laser Proximity sensor has the fastest detection, and is most reliable and not affected by the sunlight, unlike the IR Sensor. The properties of the different motion detection sensors displayed on table 1.

Name	**Method**	**Accuracy**	**Range (cm)**	**Response time**	**Light Conditions (inc. Sunlight)**	**Dark Conditions**	**Cost**
IR Sensor	Reflects (from an object) emitted IR to the sensor	Low	10-100	slow	No	Yes	~£10

Reflective Laser Proximity	Reflects laser light from an object	High	10-200	Very fast	yes	yes	~£200
Retroreflective Laser Sensor	Emits laser light and detects by reflector opposite to emitter	Very High	20-1000	Very fast	yes	yes	Up £500

Table 1- Sensor Types

The Proximity Laser Sensor does not require a receiver to be installed opposite unlike in Retroreflective arrangement. Laser LR- TB2000 by Keyence is chosen, it complies with the Class 1 Laser Safety meaning that this class of laser does not pose a threat to eyes or skin (can look at it without protective eyewear), it does not produce a visible laser beam hence it is safe to use in the students library, and is not a distraction. The sensor has a detection range of 3 cm - 300 cm which is perfect for the hallway width of 190cm, figure 3. Laser produces a green light of 505 nm. This wavelength is effective regardless of the clothing colour of the passing person(As red lasers interfere with red clothing causing inaccurate activations).The laser can be set to produce binary output of 24V for ON state and 0V for OFF state.

Cost Analysis

Cost Analysis of the system for one floor can be seen on the table 3 below.

Component	**Cost each(£)**	**Total(£)**
Laser Sensor (4)	250	1000
PCB (1)		50
7 Segment Display, large (6)	2	12
AC to DC adapter	1	10
Total		1082

Table 2 - Cost Analysis

The total cost for one system for one floor is £1082, the cost of the total system is estimated as: £4328 (without the wireless transmitter/receiver) however this is not including the installation costs, assuming that it would be done by City Universities technicians. The maintenance costs are also not included in the estimation. The energy costs can be seen in the next section.

Energy Analysis
The primary components consuming power in the system can be seen on table 3.

Component	Power Consumption (W)	Total Power (W)
Laser Sensor (4)	~1.5W each	~6W
PCB (1)	~2W	~2W
7 Segment Display, large (6)	~0.25W each	~1.5W

Table 3 - Energy Analysis

Total estimated power consumption: ~9.5W - 10W per floor
Total for all four floors: ~40W (assuming identical systems on floors 3-6)

Energy consumption estimation (assuming continuous operation):

- Daily Energy consumption per floor: 10W×24 hours=240 Wh=0.24 kWh
- Annual Energy consumption per floor: 0.24×365=87.6 kWh
- For four floors: 87.6×4=350.4 kWh/year

Considering an average electricity cost of £0.30 per kWh (UK rates):

- Annual cost per floor: 87.6×0.30=£26.28
- Annual cost for all floors: 350.4×0.30=£105.12

This suggests that the energy costs are relatively low, making it a sustainable system in terms of power consumption. To further reduce energy usage, potential optimisations include:

- Implementing a low-power standby mode when the system is inactive (e.g. overnight).
- Using lower-power seven-segment displays with energy-efficient drivers.

Sustainability Analysis
The laser sensor model used is energy efficient compared to other sensors and the camera based systems. The selected laser sensor has relatively low power usage in comparison to other counting systems. The sensors are expected to have a lifespan of at least 10 years with the minimal maintenance. This reduces the maintenance cost and electronic waste. The Laser is made by Keyence in Japan. This suggests ethical working practices. However, a few materials used in the laser sensor include plastics that are not recyclable, they are in a small quantity, and the overall impact is low. The materials for the 3D body of the main unit, should be from sustainable recyclable materials to further enhance the sustainability. All the above factors would show the City University's commitment to a more sustainable innovative future.

Privacy Concerns
The system counts the number of people that enter and/or exit the library without taking any imagery or personal details to identify the individuals. It complies with the privacy standards

as the data storage of the system is anonymous and is not linked to individuals. However, library users may not be aware that the system is not taking and storing any imagery. This needs to be disclosed to users, by placing the relevant information in the form of posters around the system.

Risk Assessment
All systems come with their risks that have different impacts. The risks and their impacts can be seen on table 4 and figure 4.

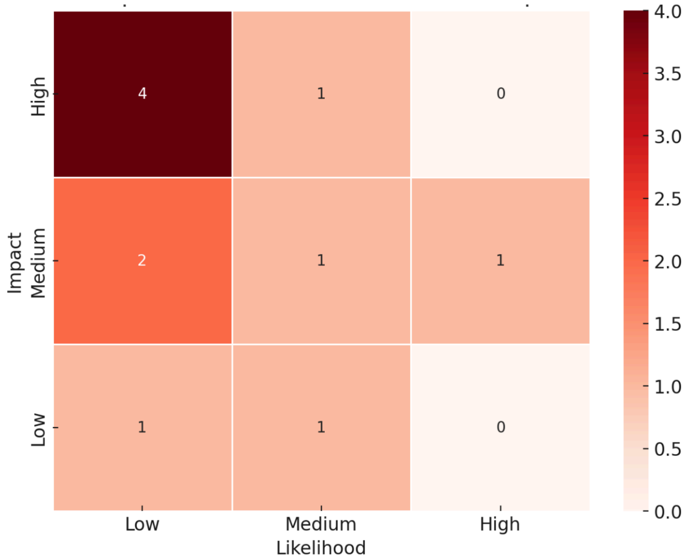

Figure 4-Heatmap of Risk Analysis

Risk	Probability	Impact	Mitigation	Impact
Sensor Failure	Low	High	Regular Maintenance	Inability to perform people detection
False Detections	Medium	Low	Optimise sensor position	Inaccurate count, misleading users.
Failure to detect correctly multiple people	High	Medium	Push button	Inaccurate count, misleading users.
People entering exceeding the 255 max capacity	Low	Low	Display “E” to display that the floor was exceptionally busy	Misleading users
System damage by people	Medium	High	Place system module in the safe space	Further technical attention required. Costs of repair may be high.
Inaccurate readings due to power failure	Low	Medium	Ensure that batteries are replaced on time, train staff.	Inaccurate count, misleading users.

A sensor being continuously obstructed	Low	High	Ensure sensors are not blocked e.g. by a wheeled bookshelf	Inaccurate count, misleading users.
Reset Button improperly used	Low	Medium	Ensure that staff are trained to operate the system	Inaccurate count, misleading users
Hardware Wear and Tear	Low	High	Routine Maintenance	PCB Degradation, Inaccurate count
System being exposed to water	Low	High	System should be in a secure place, but some new parts may need to be ordered.	Possible breakdown of the hardware and PCB requiring replacement. Laser sensors are water resistant
Communication Failure between the module/sensors /push button	Medium	Medium	Ensure that communication modules are functional, if needed order a replacement	Increased costs

Table 4 - Risk Analysis

Implementation Timeline

2 June - 8 June

- Finalising the Sensors Quote
- Doing the 3D CAD printing Model for PCB/ Sensors Holders
- Identifying the 3D Printing needs
- Agree with the department about the 3D printing arrangements

9 June - 15 June

- Converting Logisim to a PCB, designing the PCB
- Ordering the PCB from Logisim renders
- Ordering the necessarily Components (e.g. AC/DC converter to power the PCB)
- Agree with the department about the 3D printing arrangements

16 June - 22 June

- Do the 3D printing
- Assemble/solder the 3D printing components with sensors/PCB
- Mount the sensors and the system
- Wire the Sensor/ Ensure Optimal cable management

23 June - 29 June

- Test the implemented physical system using systematic approach
- Ensure optimal calibration of the sensors
- Ensure the system is not affected by noise
- Observe the system operation in real life, running full day tests

Benefits and Challenges of the system

Benefits and Implications of the system can be seen on table 5 below

Benefits	Challenges
Automated tracking- reduces need of staff to manually track occupancy of each floor	Securing funding for the project, as the initial cost for the system is high
Prevents overcrowding by navigating students which floor to use. Ease of navigation	Challenges of placements and calibration of the laser sensors
Lowers disruptions, as students do not need to walk around the floor to see if there are spaces to sit	Users Concerns- as some users may feel monitored and discouraged to use the library due to lack of knowledge about the system
Helps to make data driven decisions about library interior	Adds extra work for library workers, and extra training is needed
Shows innovation of the Engineering Department	High Energy usage of the system might be costly

Table 5 - Benefits and Challenges of a system

Overall, the system has shown to be beneficial for the navigation in the library, improving the students' experience as well as simplifying staff manual counting duties, table 5.

System Design:

The Block Diagram of the system can be seen below, on figure 5.

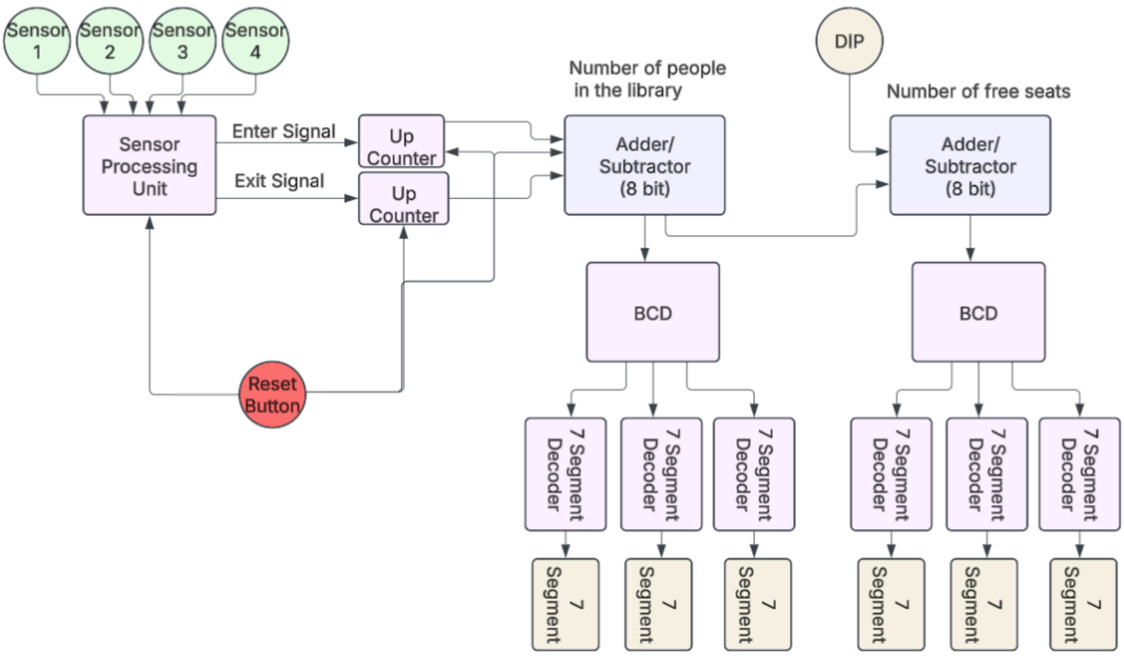

Figure 5 - Block Diagram of System Structure

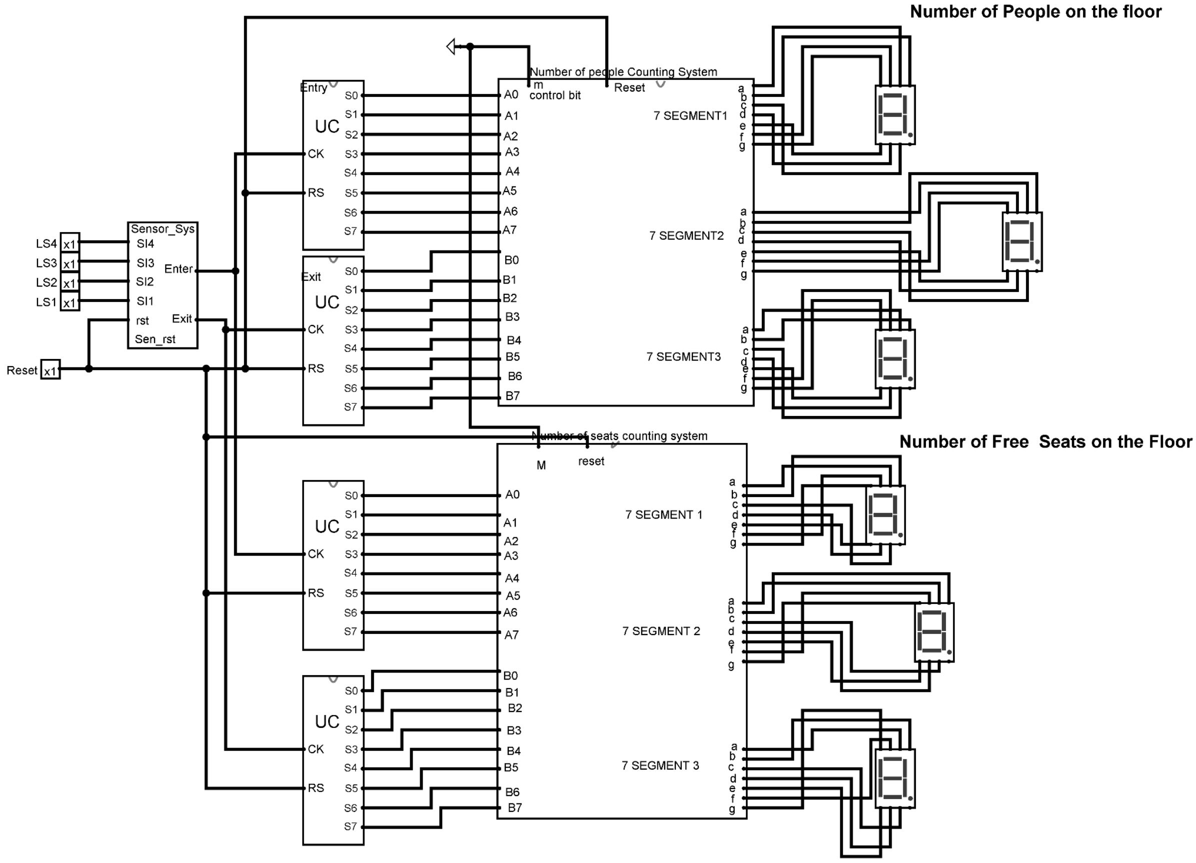

Figure 6 - Main Logisim Circuit

The final implementation of the system on figure 6. The System uses a sensor circuit to detect library Enter or Exit and then update the Up counters. The data is then passed to the Arithmetic Logic Unit (ALU) which counts the number of the possible seats and displays it on the 3 seven segment displays. Each subsystem was individually tested before integration.

Error detections by the sensor system:

The sensor Reset button ensures that all the sensors were triggered improving the accuracy of the count, it resets the people count to 0. Should be used daily by staff.

The system handles the following errors and cases:

- Simultaneous entry/exit, ensures that the system does not change the Enter or Exit output, the number of people in the library floor remains unchanged.
- Incomplete Entry/Exit is disregarded as sensors need to be activated in required order.
- Person changes direction midway (e.g. only triggering Sensor 1 and 2) and walks back, the counter remains unchanged.

Error detections by the Arithmetic Logic Unit:

The ALU reset button triggers all systems within the circuit, resetting the final display output to zero as well.

The systems handles the following error cases:

- Comparator, uses the Cout to decide whether the output is over 255.Hence, displaying error for overflow condition.

Technical Implementation:

Sensor System

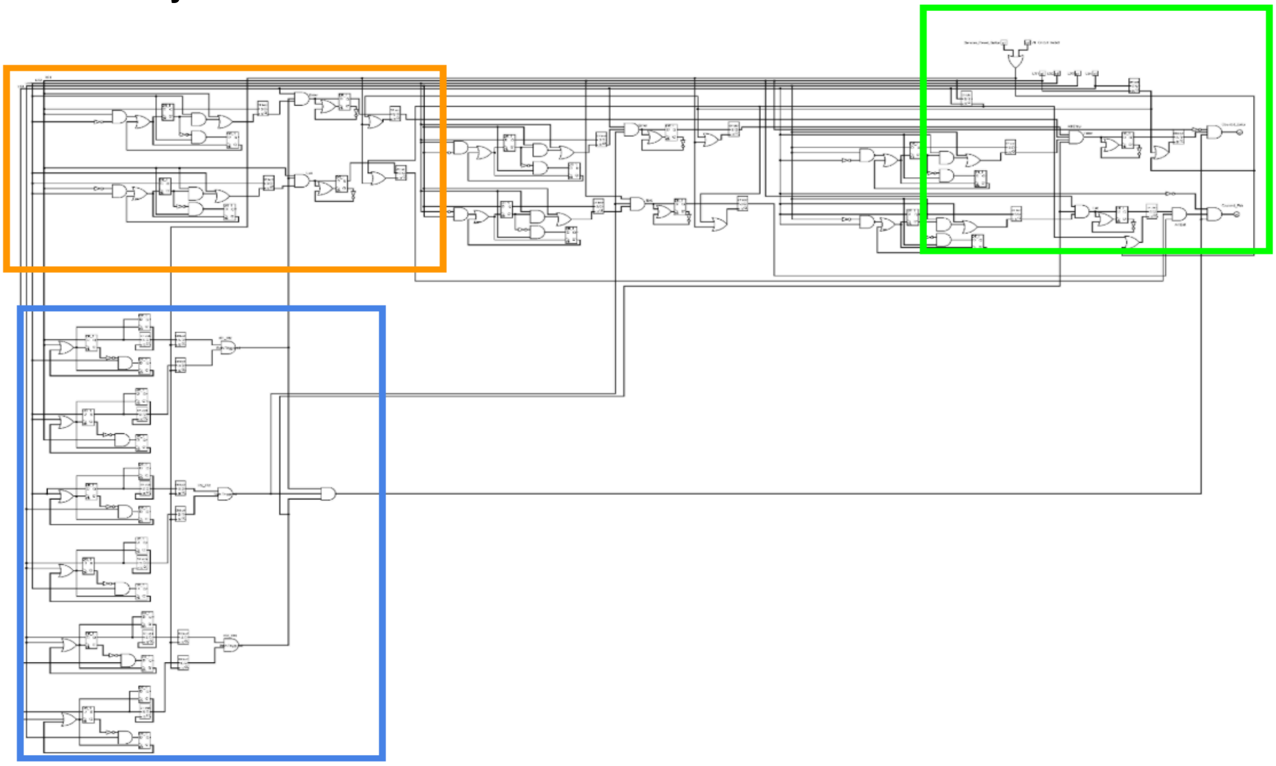

Figure 8a - The Sensor System Overview

Senor system, figure 8a, detects whether entry or exit was made, and passes that information to Up Counter. It consists of 4 laser sensors,figure 8a, based on the trigger sequence, the system decides whether an Entry or Exit was made.

Entrance: Trigger sequence is Sensor 1- Sensor 2 -Sensor 3 -Sensor 4. The sensor system outputs 1 for entrance, and keeps it until Sensor 1 is triggered again - resetting the sensor module. This ensures that if a person changes their mind about exiting the library and only triggers Sensor 4 - Sensor 3 - Sensor 2, then no change is made to the counter. The same reversed principle is applied to the Exit Sequence.

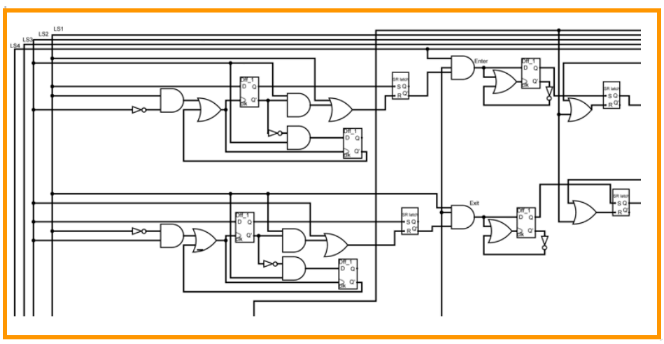

figure 8b- The orange sub system (Sequence Detection),

Sequence Detection, figure 8b, determines whether an Entry or Exit was made based on the sequence of the sensor actuations. It splits sensors into pairs: LS1 and LS2, LS2- LS3 and LS3 with LS4. When both sensors of the pair were actuated, the True value for either/entry based on the order is passed further in the circuit. The True value for each pair is stored in the D Flip flop and then passed to the long term storage to the SR latches, that are then compared to determine whether an Entry or Exit was made. Where D flip flops reset by the sensor turning off.

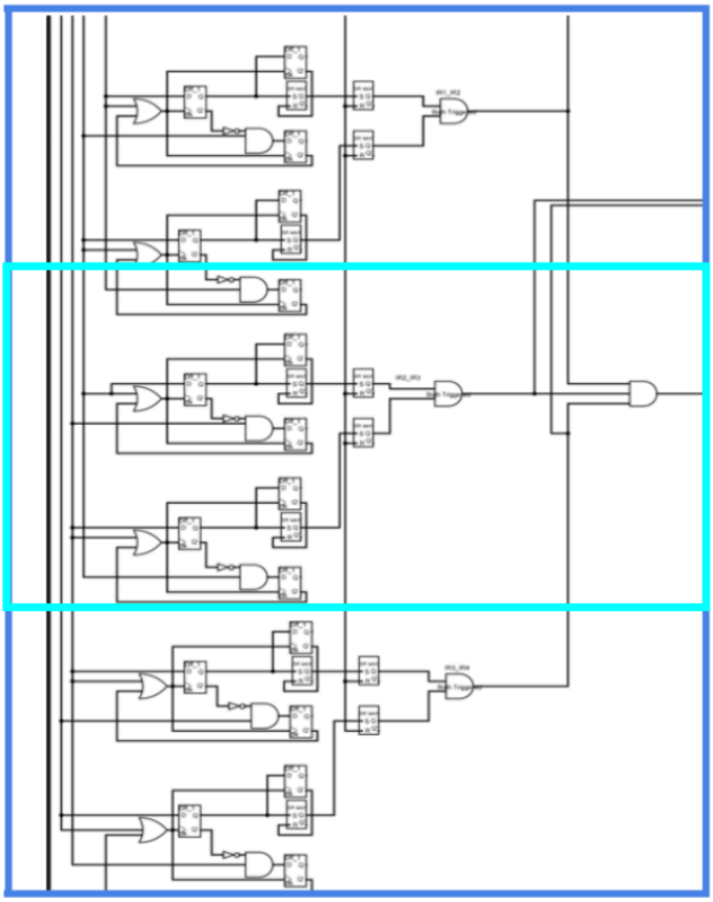

Figure 8c -The Dark blue sub system (Sensor Actuation),

The Sensor Actuation in dark blue, Figure 8c, ensures that all the sensors in the sequence were triggered. The similar principle as in the Sequence Detection system, figure 8b was used. Sensors were split in the same pairs and then verified that both sensors were triggered. The values of the triggered pair stored in SR latches and then compared. The system does not detect whether an entry/exit was made, but confirms all sensors actuations.

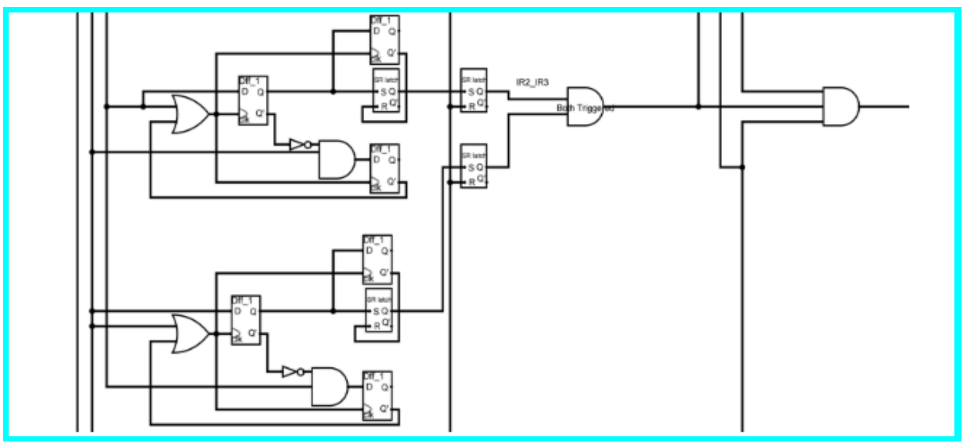

Figure 8d - Comparison Sensor Pair Circuit

The light blue box, Figure 8d, shows the zoomed-in circuit for a single sensor pair, LS2-LS3.

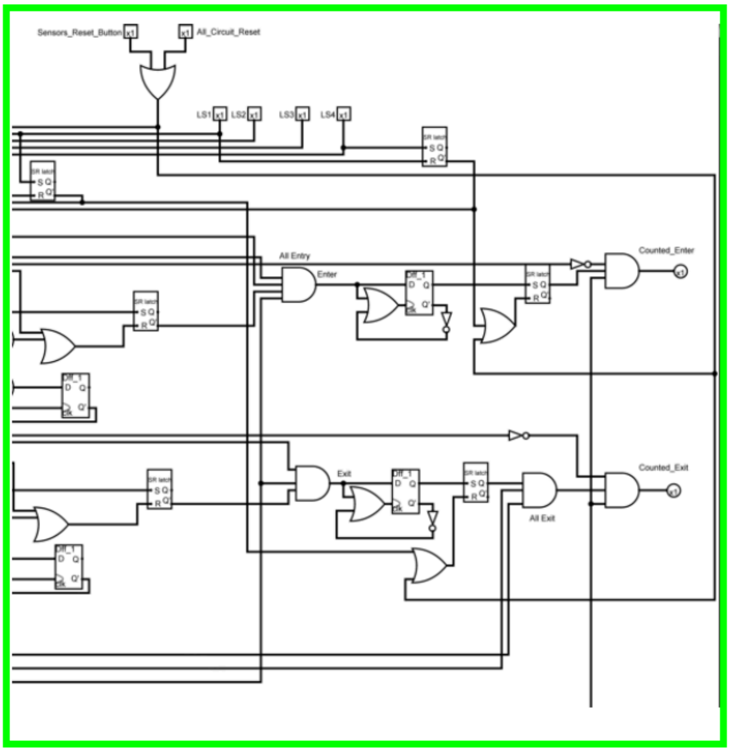

Figure 8c - Decision Logic System

The green subsystem, Decision Logic system, figure 8c, makes a final decision based on all the above subsystems' outcomes deciding whether the output is Entry, Exit or neither.
 To avoid simultaneous Entry/Exit output can not be displayed when both Sensor 1 and Sensor 4 are ON. In the case of both Sensor 1 and 4 on, the output does not change. For the SR latches in Entry circuits, resetted at Sensor 1 actuation, and vice versa for exit circuits.

Up Counter

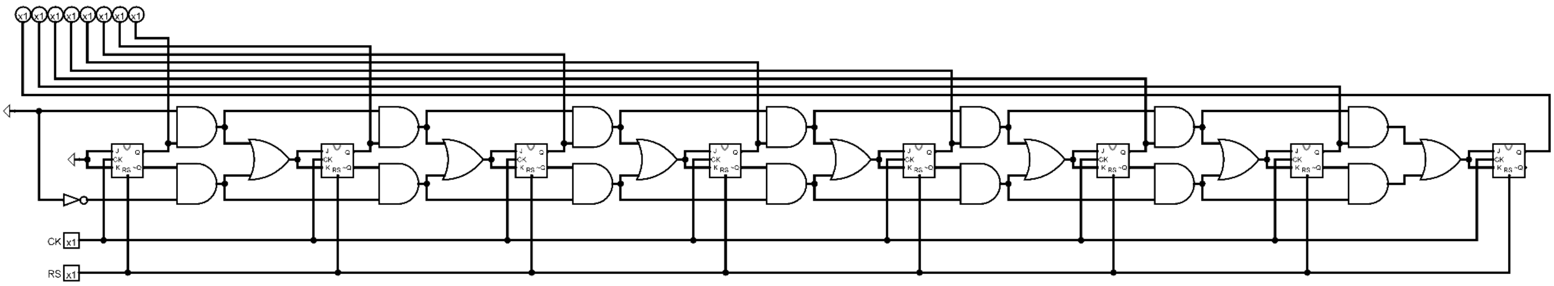

Figure 9a-Counter Circuit

The counter system consists of two 8-bit up counters, both built by cascading JK Flip-Flops and logic gates enabling it to track the number of people entering and exiting the library at different floors. Each JK Flip-Flop represents a single bit in the 8-bit binary number, so the system counts in the range from 0 to 255. As the counter receives the signal from the Sensor Processing Unit, every pulse on the signal increments the value by 1. The Q output of each flip-flop is used to determine toggling conditions for the next flip-flop. Logic gates (two AND gates and an OR gate between the flip-flops) are interconnected to control when each flip-flop toggles based on the state of the preceding ones. The same flip-flop cascading is used for both the Enter and Exit scenarios. Both counters increment independently based on their respective input signals. This logic-based design simplifies the structure and ensures reliable and accurate counting.

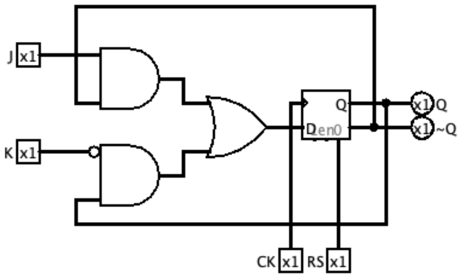

Figure 9b- JK Flip Flop

The JK Flip-Flop is constructed using a D Flip-Flop and logic gates. The logic is based on the standard characteristic equation, where two AND gates and an OR gate produce the input:

$$D = J\overline{Q} + \overline{K}Q$$

This value is then passed into the D Flip-Flop that toggles on clock (CK) pulses. Reset (RS) pin is needed to asynchronously reset the output. And outputs are labeled Q and ~Q, which are also used in chaining the counter stages.

Adder Subtractor Circuit-7 SEGMENT DISPLAYS

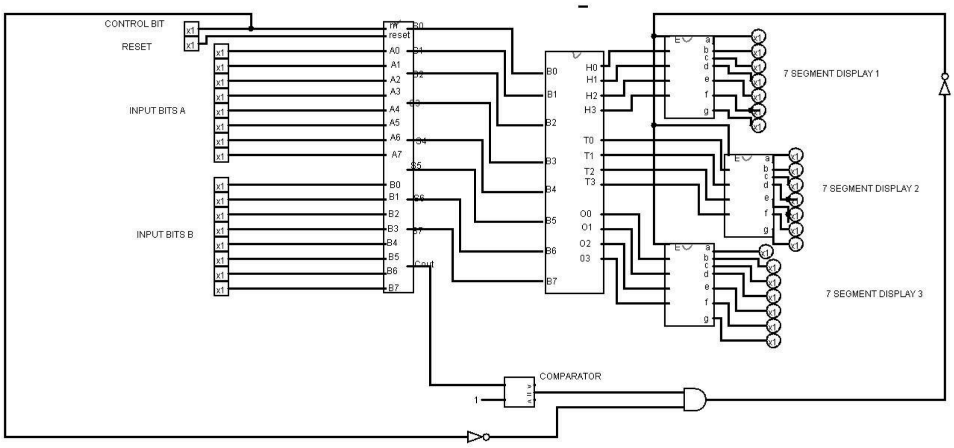

Figure 10a - Circuit for number of people in the library

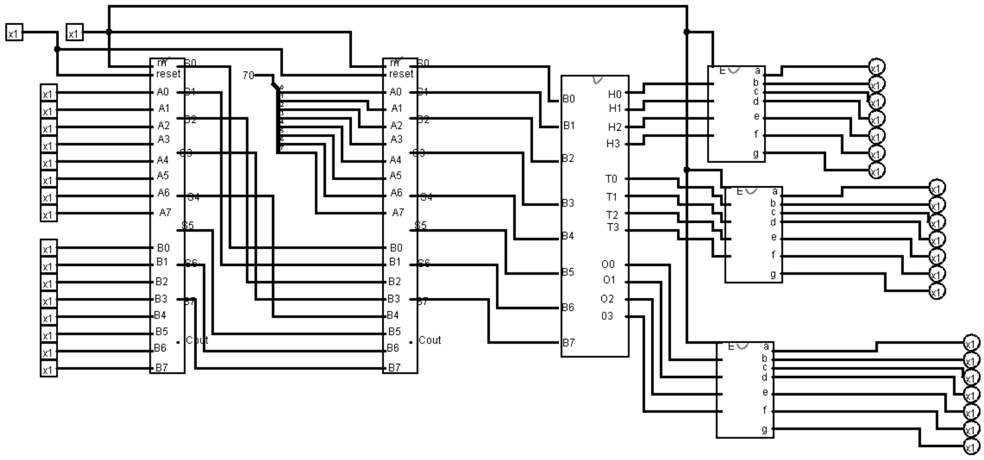

Figure 10b - Modified Circuit-To display Number of Available Seats

The circuit consists of 6 subcircuits,

1. **8 bit Adder Subtractor**- Consists of 8 Full Adders and a control bit. A reset button is used to reset the entire circuit.
   M control bit-Always set to 1, hence the circuit always performs subtraction.
   Sub circuits-
   - 4 Full Adders
   - Half Adders are used to build the Full Adder

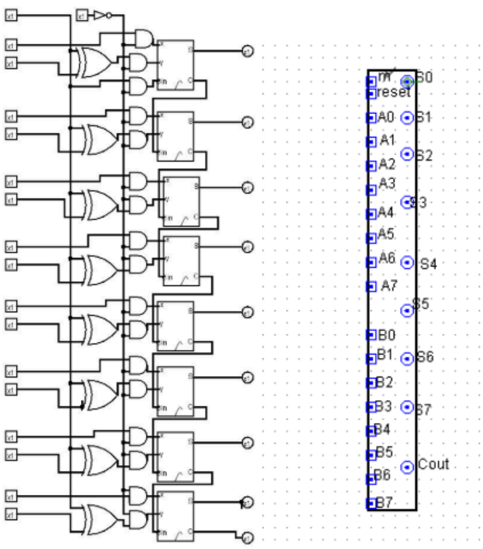

Figure 10c-Adder subtractor circuit

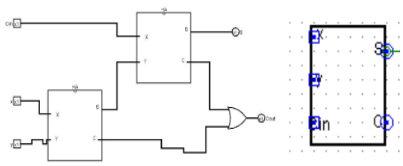

Figure 10d-Full adder circuit

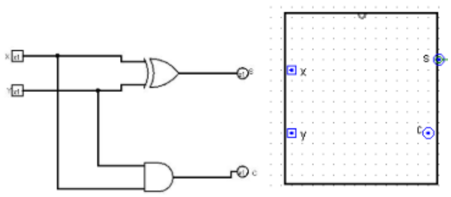

Figure 10e-Half Adder Circuit

2. **8 BIT Binary to Decimal**- The BCD takes the outputs of Adder Subtractor circuit, to convert it into a 3 digit decimal number. It uses the general arithmetic principle of splitting the number by using division properties.
    - Divide the number by 100, quotient is 4 bit output given as input to 7 segment decoder.
    - Remainder is divided by 10, to give the tens output which is given as input 7 segment decoder.
    - Remainder of the second division is given to a modulus circuit to output the 4 bit binary which represents the ones digit.

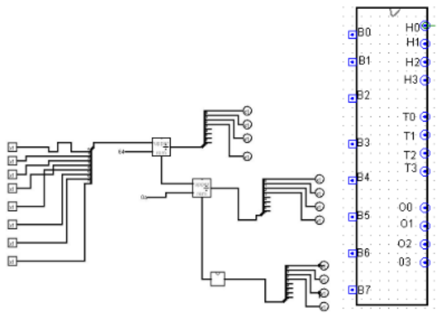

Figure 10f -8 bit binary to decimal

3. **7 Segment Decoder**- Takes 4 bit binary representations of the Hundreds,Tens and Ones digits respectively and converts them to the corresponding representation for the 7 Segment Display.
Enable- The Enable is used for error handling. Since we are dealing with 8 bit numbers the highest value the circuit can accurately perform arithmetic operations to is 255(2^n-1).
When the Enable is on the decoder functions normally.
When the Enable is off it displays E on all LED’s indicating a value > 255.

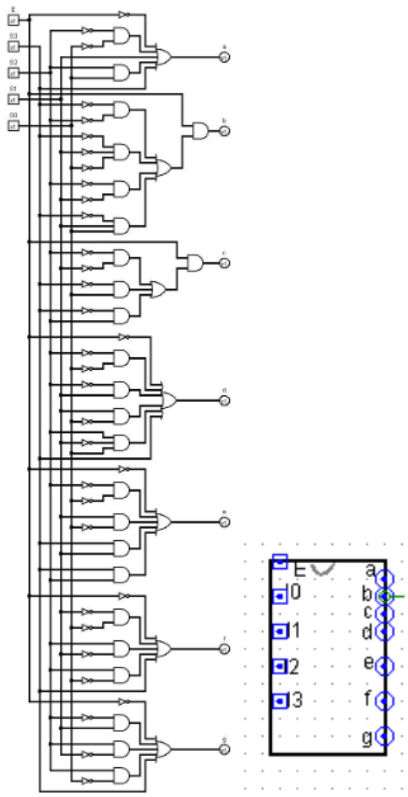

Figure 10g-7 segment decoder

4. Comparator- The comparator output is connected directly to the enable. It compares Cout of the Adder to 1,and if it is equal gives a positive output indicating that the number is greater than 255.

- This works accurately for addition since Cout=0 for all values<255 and Cout=1 for all values>255.
- The same logic cannot be used for Subtraction since Cout is always = 1 as an indicative of borrow.
- Hence an AND gate is used with Inverted Control Bit(M) indicating that the value going to Enable will be 1 only when Cout=1 AND the circuit is in Addition mode.
- We don’t require a condition for subtraction because we will always be dealing with numbers within the range 0-255.

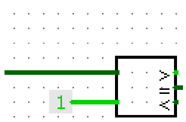

Figure 10h-Built in Logisim Comparator

Modified Circuit- The Modified circuit uses the same subcircuits as the one used to display number of people in the library, however this circuit makes use of 2 Subtractors
Subtractor 1: Used to subtract number of exits from number of entries to compute total number of people in the library.
Subtractor 2: This subtractor subtracts the output of Subtractor 1(number of people in the library) from constant(total number of available seats) thereby computing the total number of available seats.

The output then follows the same approach as the general circuit to display this output on 7 Segment displays.

Evaluation and Scalability:
(Sensor System)The Laser Sensor (LS) was tested for the various scenarios in Logisim, and can be seen in the table 6, below. However only the simulation of the system was tested, and the actual physical system may vary in the output.

Scenario	**Inputs**	**Expected Output**	**Actual Output**	**Pass/ Fail**
Single Person Entering	LS1-LS2-LS3-LS4	Enter - 1 Exit - 0	As expected	Pass
Single Person Exiting	LS4-LS3-LS2-LS1	Exit - 1 Enter - 0	As expected	Pass
Single Person changes mind after 1st sensor actuation	LS1-LS1	No change	As expected	Pass
Single Person changes mind after 2nd sensor actuation	LS1-LS2-LS2-LS1	No change	As expected	Pass
Single Person changes mind after 3rd sensor actuation	LS1-LS2-LS3-LS3-LS2-LS1	No change	As expected	Pass
Single Person Entering, after previous exited	LS4-LS3-LS2-LS1 LS1-LS2-LS3-LS4	Enter - 1 Exit - 1	As expected	Pass
Simultaneous Entry/Exit of 2 people	LS1 and LS4	No change	As expected	Pass
2 People Enter with slight delay	LS1-LS1-LS2-LS2-LS3-LS3-LS4-LS4	Enter -1-0-1	Enter - 1	Fail
1 person Enters and another Enters a little later (not blocking sensors simultaneously	LS1-LS4-LS2-LS3-LS3-LS2- LS4- LS1	No change	As expected	Pass
Incomplete Entry after a full entry (at 2nd sensor go	LS1-LS2-LS3-LS4 LS1-LS2-LS2-LS1	Enter - 1 - 0	As expected	Pass

back)				
Incomplete Entry after a full entry (at 3rd sensor go back)	LS1-LS2-LS3-LS4 LS1-LS2-LS3-LS3-LS2-LS1	Enter - 1 - 0	Enter -1 - 0 Exit -1	Fail
Incomplete Entry after a full entry (at 3rd sensor go back, and pressed button)	LS1-LS2-LS3-LS4 LS1-LS2-LS3-LS3-button- LS2-LS1	Enter - 1 - 0	As expected	Pass
Incomplete Exit after a full Exit (at 3rd sensor go back)	LS4-LS3-LS2-LS1 LS4-LS3-LS2-LS2-LS3-LS4	Exit - 1 - 0	Exit - 1 - 0 Enter -1	Fail
Exit after a full Exit (at 3rd sensor go back and pressed button)	LS4-LS3-LS2-LS1 LS4-LS3-LS2-LS2--button-LS3-LS4	Exit - 1 - 0	As expected	Pass
Incomplete Exit (3rd Sensor) after a full Entry	LS1-LS2-LS3-LS4 LS4-LS3-LS2-LS2-LS3-LS4	Exit - 1 No change	As expected	Pass
Incomplete Entry after a full Exit (at 2nd sensor go back)	LS4-LS3-LS2-LS1 LS1-LS2-LS2-LS1	Exit - 1 No Change	As expected	Pass
Incomplete Entry after a full Exit (at 3rd sensor go back)	LS4-LS3-LS2-LS1 LS1-LS2-LS3-LS3-LS2-LS1	Exit - 1 No Change	As expected	Pass
Incomplete entry (3rd sensor) then a full exit	LS1-LS2-LS3-LS2 LS4-LS3-LS2-LS1	No change Exit - 1	As expected	Pass
Incomplete exit (3rd sensor) then a full exit	LS4-LS3-LS2-LS1 LS4-LS3-LS2-LS2-LS3-LS4	No change Exit - 1	As expected	Pass
Incomplete Exit then incomplete Enter	LS4-LS3-LS2-LS2-LS3-LS4 LS1-LS2-LS2-LS1	No change	As expected	Pass
Single Person Entering and button pressed midway	LS1-LS2-button-LS3-LS4	Enter - 1 Exit - 0	Exit - 0 Enter - 0	Fail

Single Person Exiting and button pressed midway	LS4-LS3-button-LS2-LS1	Exit - 1 Enter - 0	Exit - 0 Enter - 0	Fail

Table 6-Sensor System Test Table

The test results of the sensor system show that the sensor can detect movement of people in most everyday situations. From figure 1, it is also clear that the library almost always occupies less than a third, hence the flow of people is expected to be small. The system is reliable unless there are no groups of people entering/exiting the library.

Test Table for Counter

Scenario	Inputs	Expected Output	Actual Output	System reset	Pass/ Fail
Entry 1	1111 (all sensors activated)	00000001	00000001	No	Pass
Entry 2	1111 (all sensors activated)	00000010	00000010	No	Pass
Entry 3	1111 (all sensors activated)	00000011	00000011	No	Pass
…	1111 (all sensors activated)	…	…	No	Pass
Entry 255	1111 (all sensors activated)	11111111	11111111	No	Pass
Overflow	x > 255	11111111	00000000	Yes	Pass
Exit 1	1111 (all sensors activated)	00000001	00000001	No	Pass
Exit 2	1111 (all sensors activated)	00000010	00000010	No	Pass
Exit 3	1111 (all sensors activated)	00000011	00000011	No	Pass
…	1111 (all sensors activated)	…	…	No	Pass
Exit 255	1111 (all sensors activated)	11111111	11111111	No	Pass
Overflow	x > 255	11111111	00000000	Yes	Pass

Table 9-Counter Test Table

The table shows test cases for both the Enter and Exit scenarios. Each counter independently receives sensor inputs (1111 indicates all four sensors activated in proper sequence). And after the 255th entry, the output of 11111111 in the workflow scenario as expected, but in practice the system performs a reset and rolls back to 00000000.

ALU(Arithmetic Logic Unit) Test Table

Inputs	Outputs	Pass/Fail
Input 1-200(11001000) Input 2-150(10010110) M=1(Subtraction)	Hundreds-0000 Tens-0101 Ones-0000 **Decimal:050**	Pass
Input 1-250(11111010) Input 2- 5(00000101) (M=0 Addition)	Hundreds-E Tens-E Ones-E **Error(Overflow)**	Pass
Input 1-00000110(12) Input 2-00000010(4) Reset=1	Hundreds-0 Tens-0 Ones-0 **The system responds to reset signal,**	Pass
Input 1-00000000(0) Input 2-00000001(1)	Displays a random output. System not conditioned to deal with underflow,	Fail However, this is because in reality there will never be a scenario with more exits than entries hence negative output is not possible.

Table 7-ALU Test Table

This test table individually tests the Adder subtractor, BCD and 7 Segment display to accurately display the decimal outputs for 8 bit dummy inputs.
The only scenario in which the circuit fails is when it has to deal with underflow, which the circuit cannot realistically encounter. Hence, the circuit shows high accuracy for all real world scenarios.

Final Circuit Test Table

Scenario	Inputs	Outputs	Pass/ Fail
4 Entries,2 exits	Counter 1-00000100 Counter 2-00000010	Hundreds-0000 Tens-0000 Ones-0010 Decimal:002	Pass
3 entries,1 exit,2 entries	Counter 1-00000101 Counter 2-00000001	Hundreds-0000 Tens-0000 Ones-0100 Decimal:004	Pass
150 entries-11	Counter 1-Error (	Hundreds-E	Fail- However this

exits-115 entries	value is over 255) Counter 2-00001010	Tens-E Ones-E Error	floor of the Library does not receive more than 254 overall entries in a day hence can be used in real world scenarios.
255 Entries	Counter 1-11111111 Counter 2-0000000	Hundreds-E Tens-E Ones-E Error	Pass- Indicates there are 255 people in the library hence the library floor is Full.
Rapidly alternating 1 entry-1 exit-1 entry-1 exit	Counter 1-00000010(2) Counter 2-00000010(2)	Hundreds-0 Tens-0 Ones-0 Decimal:000	Pass - Test shows system can handle quick signal changes

Table 8-Final Circuit Test Table

The test table uses test cases to show that the ALU unit handles all entry and exit scenarios accurately, effectively displaying a 3 digit decimal output to represent the total number of people and the number of available seats.

Scalability

Each library floor, 3-6 has the capacity ranging from 112 to 299 as on table 1. The primary floor of the system is 4th, with 112 seats. However the system is designed to be scalable to all the floors.

The system uses 8 bits for all calculations within the program and hence it can go up to 254. The main focus of this project was to develop a system for one floor with the scaling possibility. The resulting system is most accurate for floor 3,4 and 5, with scalability to all other floors. Floor 6 is the only floor which offers more than 254 seats, however this scenario is highly improbable, as seen in figure 2.

While this data is taken not during the exam period for general use case scenarios, it would not be sustainable to develop an extra system to cover 9 bits, as it would complicate the system as well as increasing the power consumption and the increased hardware complexity of the system, hence decreasing the sustainability.

Scaling the system up will not change the sensor position and their order, as the library entrance hallway is the same dimensions, however floor 3 has a toilet in the hallway while this will not affect sensor position.

Each floor will have an independent sensor unit that tracks entry and exit, computes seat availability, and displays the information locally using 7-segment displays. To avoid the need for daily manual resets on every floor, all units will be connected via the central LoRa(LongRange) transmitter/receiver module, RFM95, as well as the 7 segment screens. Screens would be displayed on the 2nd floor - The library Entrance. The module with the reset button would be located at the main reception and when pressed, it will broadcast a reset signal wirelessly to all floor units.

Long Range Audio penetrates walls and floors easily, ideal for a multiple floor library. It consumes low power and does not require complex infrastructure of any kind. Hence it is easily scalable as well.
The Head Count and Seat Availability System provides an efficient monitoring of library occupancy in real time. The system successfully displays the number of people and number of available seats on all 4 floors. Throughout testing across different scenarios, reliable performance was achieved with effective error handling and reset functionality. Overall, our system meets the objective of improving library navigation and operational efficiency, while remaining technically robust and user-friendly.