MACQUARIE University

School of Engineering

Scoping and Requirements Document

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T1 Comms 3

Session 2 2023

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Revision Log

Revision Number	Release Date	Author	Description
0.1	29/07/2023	T1 Comms 3	Initial draft of Scoping Document
1.0	08/08/2023	T1 Comms 3	Scoping Document updated with all required components
1.1	12/08/2023	T1 Comms 3	Adjustments based on feedback from teammates
1.2	16/08/2023	T1 Comms 3	Changes made based on feedback from buddy marking
1.3	19/08/2023	T1 Comms 3	Formatting changes to refine document structure

Introduction

This document outlines the scope of the design and construction of a component of a machine which comes together as a larger kinetic sculpture. The goal is to create a functionally and visually captivating sculpture that will serve as the focus of entrance of the University's main engineering building. The sculpture will consist of multiple interconnected cubes, each processing marbles and contributing to an overall mesmerising kinetic display.

This document's purpose is to provide stakeholders with a clear analysis of the software requirements, constraints, and scope of the project division being handled by T1C3. In collaboration with the motion and structure team, we will be responsible for the design of one of the cubes that will construct the Marble Machine. As the Communications team of this cube, we are responsible for the software design, development, and implementation aspects. This document includes all the elements of a preliminary assessment of the problem such as the functional, performance, and interface requirements, constraints, inclusions, exclusions, and the deliverables that are expected from our team.

Contributors

The Engineers for Box 3 are a team of MQ Undergraduate Engineering students who strive to create the most ambitious kinetic sculpture for the university. Working alongside members from the two other streams, T1_Motion_4 and T1_Struct_2, below are the members of the T1_Comm_3 team.

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Figures and Tables

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Glossary

Term	Definition
MDF	Medium-Density Fiberboard
LED	Light Emitting Diode
TPM	Technical Performance Measure
AUD	Australian Dollar
Arduino	An open-source electronics platform based on easy-to-use hardware and software.
Uno	Refers to Arduino Uno, a microcontroller board.

1 - Problem Definition

The Macquarie School of Engineering has requested T1C3 to design and construct various subsystems for its Massive Marvellous Multiple Marble Machine (hereinafter referred to as *the machine*), a kinetic sculpture composed of various boxes with unique functional mechanisms. The machine is to be an interdisciplinary effort between a large number of engineering students, who have been designated to ‘Structure’, ‘Motions’ and ‘Communications’ teams.

Each box to be included in the machine must be sized 250 mm by 250 mm by 250 mm, and is responsible for carrying a marble from one face of the box to its opposite side. It is expected that the internal traversal of the marbles is to be aesthetically pleasing, operate with a high reliability, and function for a prolonged period of time.

Each box is to act as a ‘unit’ in the machine, where they must carry a marble to another box at fixed intervals. Furthermore, it is expected that our box must initially hold entering marbles still for at least 0.5 seconds. Provided that there is a system failure in a previous box, there is also a possibility that our unit may have to handle marbles coming at random intervals. This suggests that our team is to fulfil two distinct tasks:

- Carrying a marble from one face of the cube to its opposite end.
- Handling marbles at the ‘entrance’ of the cube, either at fixed or potentially random intervals.

The Macquarie School of Engineering has allocated $100 for Team 1 to use as a budget for the project. It is expected that this budget will be used to fund the structure of our box, the internal mechanisms of the box that will physically move the marbles, and hardware/ electronic components that will supplement the project (e.g. an Arduino board, LED’s, and electronic components).

As the Communications group for Team 1, we have specifically been requested to design and handle the software components of our given machine unit. This largely includes developing software for the Arduino, which will be connected to servos, motors, LED’s, and sensor components. Given the nature of our client's request, we expect that we will need to program an assortment of sensors and motors to dictate how the marbles entering the machine will be handled before going into the motions mechanisms. Furthermore, we will also have to program a set of LED’s in a manner which makes our groups box aesthetically pleasing. Although the motions team will largely be responsible for wiring these components to the Arduino, we will be responsible for programming the board and its components.

2 - Requirements

2.1 Functional Requirements

The functional requirements outlined below cover the basic requirements set by the customer for our system to perform as a whole. These include requirements that fall within as well as outside of the technical scope of T1C3, for the purpose that this document shall serve as a source of truth for all parties involved. Explicit declarations of inclusions and exclusions are made further in this document.

Requirement ID	Requirement Description
FR-Req01	The cube shall have the external dimensions of 250mm by 250mm by 250mm
FR-Req02	The cube shall mount to the larger sculpture using only the four specified mounting positions
FR-Req03	The cube shall provide visual indication using LEDs as to the function being performed
FR-Req04	The cube shall access external services, such as power or telecommunications, only through the service port shown

FR-Req05	The cube location on the backing board SHALL be in the middle of a square 265mm horizontally by 265mm vertically, implying there is a 15mm distance between cubes
FR-Req06	The cube shall be designed to accept marbles that are solid steel spheres of 16mm diameter
FR-Req07	The cube shall accept marbles that are spaced no closer than 1 second apart through the opening port
FR-Req08 (level requirement)	The cube shall accept a marble through an agreed input opening on a surface other than the top surface of the cube
FR-Req09 (level requirement)	The marble shall be held stationary in all physical dimensions for a minimum of 0.5 seconds in time
FR-Req10 (level requirement)	The cube shall expel all marbles out through an exit opening on a different surface to that where the marble entered.
FR-Req11 (level requirement)	The cube shall control the marble in such a fashion that the bottom of the exit opening is at least 100mm higher than the top of the input opening
FR-Req12	The cube shall be manufactured from 3mm MDF for the back and side pieces, and the front shall be transparent
FR-Req13	The front surface, if any, shall be easily removable for maintenance purposes
FR-Req14	The cube shall only make use of the forces of gravity and electricity. There shall not be any use of liquids or compressed gases.
FR-Req15 (level requirement)	The cube shall not deliberately expel marbles at a speed significantly higher than that attributable to gravity alone.
FR-Req16	The cube shall have a bill of materials which totals to less than AUD$100

Table 2.1: Functional Requirements

2.2 Performance Requirements

The performance requirements outlined below are to ensure that the different components within the subsystems accomplish the required functional requirements under the given constraints to achieve optimum customer satisfaction. They shall measure how well the software system performs to achieve the functional requirements outlined above.

Requirement ID	Requirement Description	Related Functional Requirement
PR-Req01	The cube shall accept marbles of less than or equal to 16mm diameter, that are made of materials lighter than steel	FR-Req06
PR-Req02	Codes shall be readable and well documented	FR-Req03
PR-Req03	The chosen electronic components shall be sufficiently reliable to run for extended durations as desired by the customer	-
PR-Req04	The program shall rely primarily on variable data from sensors rather than concrete values	FR-Req03
PR-Req05	The program will be optimised to use the least amount of resources	FR-Req03
PR-Req06	The system shall be constructed out of sustainable and/or decomposable materials, wherever applicable.	-
PR-Req07	The system shall maintain a certain degree of aesthetic appeal	FR-Req03
PR-Req08	The subsystems shall be easily maintainable, and accessible for convenient maintenance	FR-Req03

Table 2.2: Performance Requirements

2.3 Interface Requirements and Sign-Offs

Requirement ID	Requirement Description	Sign-offs
IR-Req01	**Construction:** T1S2 shall construct and mount the box, as well as install/mount all hardware (motors, servos, LEDs,	Ryan Ladrak - 45947422

	spiral) required to fulfil the customer requirements.	
IR-Req02	**Maintainability:** T1S2 shall ensure the easy accessibility of electronic components (Arduino Uno) so that T1C3 may carry out maintenance procedures conveniently.	Ryan Ladrak - 45947422
IR-Req03	**Connection:** T1M4 shall provide electrical connection among all hardware (motors, servos, LEDs, main power source) required to lay the ground for T1C3's programs to function.	Daniel Raciti - 46626735

Table 2.3: Interface Requirements

3 - Constraints

ID	Constraints	Description
C-1	Time	The project needs to be completed in 13 weeks.
C-2	Cost	The budget for the project is only $100 AUD.
C-3	Skill	The skill needed to complete the project is limited to the skills of the team members.
C-4	Code	The programming language must be Arduino compatible.
C-5	Level	The team must strictly abide by the level requirements chosen at the start of the semester.
C-6	Power Supply	The power supplied to the cube has to be within a voltage range.
C-7	Power Supply	The cube can not connect to the external power supply through any other point except the service port specified by the customer.

Table 3: Constraints

4 - Project Schedule

The Marble Machine needs to be developed, tested and integrated all within 13 weeks. There is a timeframe allocated for each stage of the project, such as the conceptual design to be finalised within the first 3 weeks alongside working on the Scoping Document. We hope to integrate our code into the system in week 8 to 10 which would give us two weeks to work on the testing of the cube along with error fix, resulting in a successful Marble Machine.

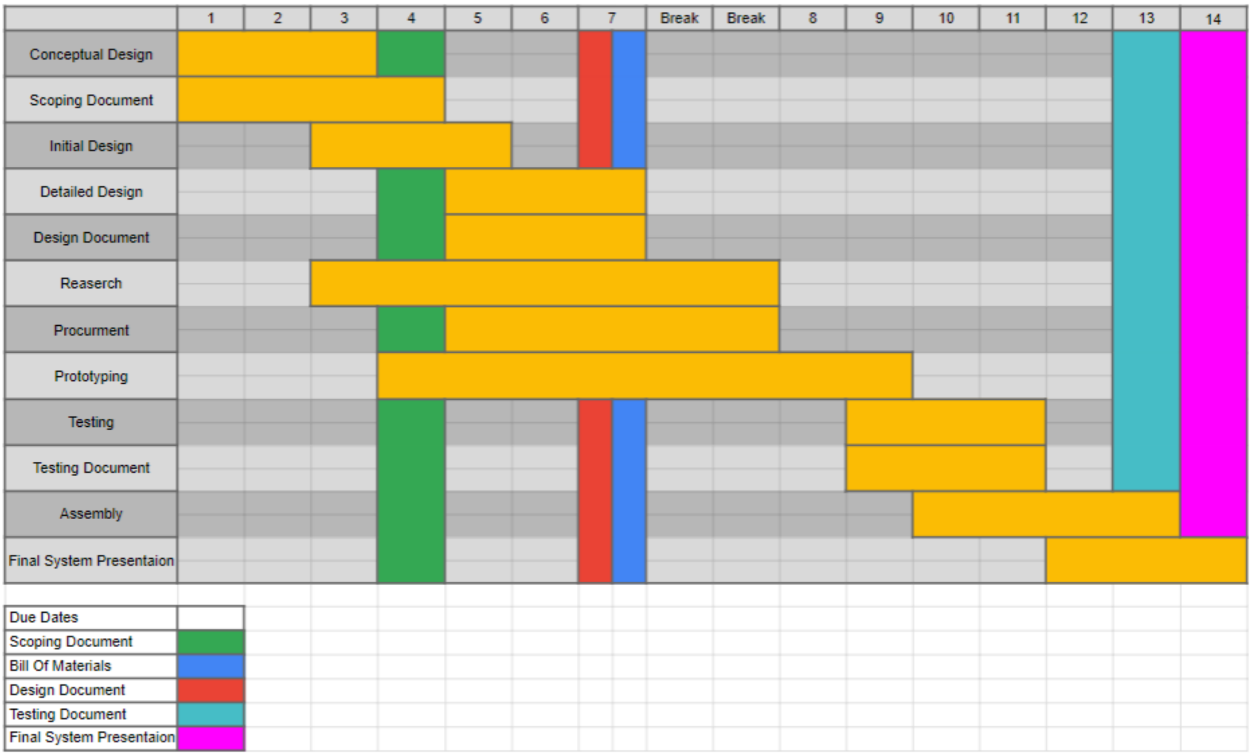

Table 4: Project Schedule

5 - Subsystems

In our implementation of the Machine, T1C3 has agreed to group up with a ‘Structures’ and a ‘Motions’ team to accompany our design of the box. These teams have formulated a conceptual design for the machine, and have divided its features into an assortment of subsystems. These subsystems have been organised between the three teams as followed:

Structures:

- ***Physical structure of the cube:*** Team one's unit is to be contained within a 250 mm by 250 mm by 250 mm cube that is made out of 3mm MDF.
- ***Compatibility of structure components with motions:*** Provides a foundation for the motions teams components to operate on.
- ***Opening rail mechanism:*** Marbles entering the machine will be processed in a forked rail mechanism, after remaining stagnant in space for at least 0.5 seconds.
- ***Structure for the spiral mechanism:*** marbles will enter a rotating spiral mechanism after traversing through the railings. The spiral itself will be stylised as a staircase, making the structure visually appealing.
- **Integration with other subsystems:** Collaborating with other teams to ensure that the structural design accommodates other teams subsystems

Motions:

- ***Electronic Components for the spiral mechanism:*** Rotates the spiral 'staircase', that will both add functionality to our machine, while also creating a visually appealing effect.
- ***Gears, motors, servos, actuators and other components that enable the marble's motion:*** Using these to create a coordinated movement and interactions between the other cubes
- ***Wiring the above components:*** Efficient and effective use of wires to connect all modes of interfaces

Comms:

- **Software design, development and implementation:** Enables all the electronic components to function and work seamlessly with each other
- **Real time response:** Proper coding makes sure the system can tackle events as they occur
- **Error handling:** Makes sure the system can handle unforeseen errors and deal with them
- **Fault tolerance:** Makes sure the system does not break down in the face of unforeseen faults

Overall, several teams play distinct roles to create the kinetic sculpture. The Structures Team is responsible for physically designing and constructing cubes, ensuring stability and compatibility with mechanical and electronic elements. The Motion Team manages mechanical aspects, designing motion mechanisms and ensuring synchronised movement, collaborating with the software team. The Communications Team handles selecting electrical components, software design and development for a cube, managing movement, interactions, and coordination with other cubes. ***All teams as a whole have to focus on visual appeal, testing and quality assurance.***

6 - Scope of works

6.1 Deliverables

The engineering students are going to attend an engineering project practice for this semester. This will allow us to hand out all the documents, outcomes and files along with evidence and that includes resources. All in one for the project deliverables.

Functional Cube Components: The fully functional cube components are to be designed such that they process the marbles while providing a visually immersive experience. Each cube stands as a testament to the successful culmination of different engineering principals.

Comprehensive Documentation: Our documentation compilation leaves no aspect unaddressed, documenting the complete trajectory of the cube's creation. It commences with the inception of initial design concepts, navigates through the construction phase, and culminates in the seamless alignment of the cube's diverse elements.

Guidelines for Difficulty: We have thoughtfully formulated explicit guidelines to facilitate teams in the selection and commitment to specific difficulty levels for their respective projects. These guidelines provide a structured framework to navigate the challenges that lie ahead.

Presentation and Demonstration: A presentation that unravels the enchanting effects of the kinetic sculpture's cube components. Live demonstrations will showcase the culmination of collaborative efforts undertaken by our teams.

Evidence of Accomplishment: Intertwined within our delivery is a comprehensive compilation of evidence, underscoring the successful realisation of pivotal project aspects. This compilation encompasses a spectrum of visual media, including images, videos, and pertinent data, which collectively substantiate our achievements.

This engineering project serves as a platform not only to demonstrate our technological insight but also to highlight the profound artistic sensibilities interwoven into every facet of this endeavour.

6.2 Inclusions

Within the comprehensive scope of the project, the responsibilities of T1C3 are focused on fulfilling the functional requirement FR_Req03, specifically addressing the LED visual component. In alignment with this objective, the scope of work for T1C3 encompasses the following critical aspects:

LED Programming: Developing a sophisticated LED system that orchestrates the lighting patterns in synchronisation with the movement of marbles throughout the cube's internal structure.

Dynamic Visualization: Designing an engaging visual experience by meticulously controlling the LED behaviour, ensuring a seamless and immersive interplay between the marbles' motion and the dynamic lighting effects.

Integration: Collaborating with other team components to seamlessly integrate the LED visual component with the overall functionality of the cube, ensuring a cohesive and harmonious kinetic display.

ID	Inclusion
IN-1	Code for sensors so that they can read and process data.
IN-2	Code for the LEDs for an illumination system that synchronises with the movement of the marble.
IN-3	Code for the motors and servos.

Table 5: Inclusions

6.3 Exclusions

In accordance with the defined scope of T1C3's role, the following elements are explicitly excluded from our responsibilities:

Structural Construction: The physical construction and assembly of the cube's mechanical structure are beyond the purview of T1C3. This includes tasks related to materials, assembly techniques, and physical stability.

Bill of Materials (BOM): The generation and maintenance of a comprehensive BOM for components outside the domain of communication systems are excluded from our scope. The BOM shall focus solely on the components pertaining to communication and LED functionality.

Mechanical Test Metrics: While we are deeply engaged in the LED visual aspect, T1C3 is not responsible for establishing test metrics or procedures for evaluating mechanical components' performance or reliability.

Maintenance Plans: The development of maintenance plans, both for mechanical and electrical components, is not within the scope of T1C3. Our concentration lies exclusively in creating a captivating LED visual experience.

Electrical Wiring: Detailed electrical wiring and circuit design for the entire cube, beyond the scope of communication and LED lighting, are excluded from our responsibilities.

Physical Interactions: Any physical interactions or mechanisms involving the marbles' movement, such as propulsion or transport mechanisms, fall outside our scope of work.

By focusing on the intricate design and control of LED visual effects, T1C3 aims to contribute a vibrant and visually immersive component to the kinetic sculpture, enriching the overall experience.

6.4 Assumptions

- **Availability of resources:** It is assumed that the resources and techniques necessary for the design and construction of the cube are readily available
- **Rate of Marbles:** No faster than a rate of 1 marble per second
- **No external intervention:** There would not be any external intervention that would impact the normal operation of the cube
- **Collaboration:** It is assumed that proper collaboration would occur between the three teams: structs, comms and motions
- **Synchronisation:** It is assumed that all the cubes would communicate with each other and synchronise their operation
- **Marble size:** It is assumed that the marbles will be a known constant size
- **Enough time:** It is assumed that all the other teams will complete their sections in the proper time frame so that comms can have enough time to design, integrate and test their code

6.5 Project Outcome

The outcome of this project is to deliver a functioning Marble Machine that meets the functional and aesthetic requirements of the customer, outlined earlier in this document. The end goal is to build a machine that exhibits a LED light show as the marble passes through certain obstacles which will be triggered by a series of mechanical and gravity-driven mechanisms, such as the marble will stay stagnant as it enters the cube for 0.5 sec and then go through a spiral that will be used to elevate the marble while the LED light show will display certain colours indicating the movement of the marble.

The ultimate success of the machine will be defined by its ability to reliably transport the marble from the starting point to the end point through its intricate pathways along with its ability to handle any errors, its aesthetic appeal, and the engagement it fosters through the combination of artistry and engineering.

6.6 Documents and Digital Submissions

All relevant documents and submissions will be provided to showcase the completion of the project. These may include:

- Detailed design documents for the cube's structure, motion mechanisms, and software components.
- Schematics, diagrams, and drawings illustrating the cube's construction and internal components.
- Code documentation and comments explaining the software design, functions, and modules.
- Visual presentations demonstrating the functioning of the cube and its interaction within the larger kinetic sculpture.
- Digital files of code, designs, and other project-related materials for future reference or modification.

Scoping Document

The Scoping Document serves as a foundational contract that establishes the project's framework and boundaries. It defines the project's scope across multiple dimensions, including problem statement, constraints, deliverables, detailed requirements, and justifications. This document acts as a roadmap for planning and execution, providing a clear understanding of the project's objectives and guiding the project team throughout its lifecycle. Additionally, it incorporates a testing schedule and a timeline of works, ensuring that the project progresses systematically.

Design Document

The Design Document is a comprehensive compilation of project plan drawings and schematics, intended to vividly convey the final layout and arrangement of the kinetic sculpture to the client. This document showcases how all the included services and components will come together in the finished sculpture. By presenting visual representations of the design, it provides a clear visualisation of the sculpture's aesthetics and functionality, allowing the client to grasp the essence of the project.

TPM Testing Document

The TPM Testing Document entails a systematic and detailed testing methodology that gauges the actual performance of the designed kinetic sculpture. It encompasses success and failure criteria that align with the predefined technical performance measurement (TPM) values initially set as project requirements.

Final Presentation

The Final Work is the culmination of efforts and the physical outcome of the kinetic sculpture project. It represents the realisation of the project's goals and objectives, bringing together various elements to create a captivating and functional kinetic sculpture that serves as the centrepiece of the university's engineering building entrance.

7 - Testing

7.1 Technical Performance Measures (TPM)

T1C3 has developed an assortment of Technical Performance Measures (TPM’s) to quantitatively test the robustness of the machine. These TPM’s have been designed to reflect the given requirements and constraints of the system, and the machine will subsequently be tested against these benchmarks. Gauging the performance of the machine relative to these TPM’s will indicate the effectiveness and security of the machine, and corrective measures can be implemented pre-emptively if any deficiencies are recorded.

TPM Code	TPM Title
TPM_01	Sizing of the cube
TPM_02	Code Quality and Readability

TPM_03	Reliability of Physical Components
TPM_04	Period where marble remains stagnant
TPM_05	Reliability of Sensors
TPM_06	Synchronisation of LED system

Table 6: List of testable Technical Performance Measures

TPM Code	TPM_01
Name of TPM	Sizing of the Cube
Purpose of TPM	To ensure that the machine directly satisfies the clients sizing requirements. Specifically, ensuring that the machine's shell is correctly sized will guarantee that it can be properly installed.
Requirements	PR-Req01
Risk Level	Medium
What Is Measured	External dimentions of the cubes frame
Procedure	Once completed the frame will be measured.
Success Threshold	The frames dimension is +- 1mm of 250 in all dimentions
Failure Threshold	The frames dimension is +- 3mm of 250 in any dimentions
Possible Causes for Error	Negligence in accounting for tollerances in machining and assembly

TPM Code	TPM_02
Name of TPM	Code Quality and Readability
Purpose of TPM	To ensure that our production code follows best practices and is able to be easily understood, in the event that others need to modify it in the future.

Requirements	PR-Req02
Risk Level	Low
What Is Measured	Warnings and Errors from C++ linting tooling.
Procedure	Routine inspections of the code will be made with the linting tooling, and the number of flags will be recorded. Once the code is functionally complete, there will be a final test performed to see if the threshold is passed.
Success Threshold	< 3 Warning flags
Failure Threshold	> 1 Error Flag
Possible Causes for Error	Lack of planning and laziness in the process of writing code.

TPM Code	TPM_03
Name of TPM	Reliability of Physical Components
Purpose of TPM	To ensure that the physical components will not malfunction due to errors in the code over long time periods.
Requirements	PR-Req03
Risk Level	Medium
What Is Measured	Number of malfunctions in a given period
Procedure	Regular limit testing of the code shall be preplanned, such as instigating a variable overflow to test the protections in place. Additionally there shall be an extended test in the testing period where we will count the number of issues that arise.
Success Threshold	0 Issues testing period
Failure Threshold	> 2 issues in the testing period
Possible Causes for Error	Variable overflow, faulty electrical connections, flawed hardware

TPM Code	TPM_04
Name of TPM	Period where marble remains stagnant
Purpose of TPM	By ensuring that the marble remains in place for a short period of time, we are able to reliably prepare it to move throughout the machine, such that errors are mitigated.
Requirements	FR-Req09
Risk Level	Medium
What Is Measured	Number of failed attempts to confine the marble for the required time.
Procedure	During the testing procedure 20 runs will be tested with a multitude in marbles.
Success Threshold	0 false events in testing period
Failure Threshold	> 1 false event in testing period
Possible Causes for Error	flawed hardware, different marbles behaving differently, uncertain input rate of marbles.

TPM Code	TPM_05
Name of TPM	Reliability of Sensors
Purpose of TPM	To ensure that the sensors are reliable in their detection of marbles entering the system and that they are not affected by marble size or weight.
Requirements	FR-Req01, PR-Req03
Risk Level	High
What Is Measured	Number of False Events given by sensors
Procedure	Sensors will be calibrated and tested prior to installation. Additionally during the testing period at the end of the product 20 marbles will be entered and the number of false events will be recorded

Success Threshold	0 false events in testing period
Failure Threshold	> 1 false event in testing period
Possible Causes for Error	faulty electrical connections, flawed hardware, flawed positioning of sensors

TPM Code	TPM_06
Name of TPM	Synchronisation of LED system
Purpose of TPM	To ensure that all of the LED lights are in sync with each other, not not ruin the aesthetics of the project or send conflicting messages to onlookers
Requirements	FR-Req03, PR-Req03
Risk Level	Low
What Is Measured	Number of desynchronization of LED system
Procedure	During the development of the LED system testing should be made at every major revision, additionally in the testing period any desynchronisation will be logged
Success Threshold	0 desynchronisation in testing period
Failure Threshold	> 1 desynchronisation in testing period
Possible Causes for Error	faulty electrical connections, flawed hardware, flawed code

References

- Macquarie University. *ENGG4001 Department of Engineering, Macquarie University. Scoping Document Sustainability in Grenfell, Weddin Shire NSW*. 2022.

Appendix

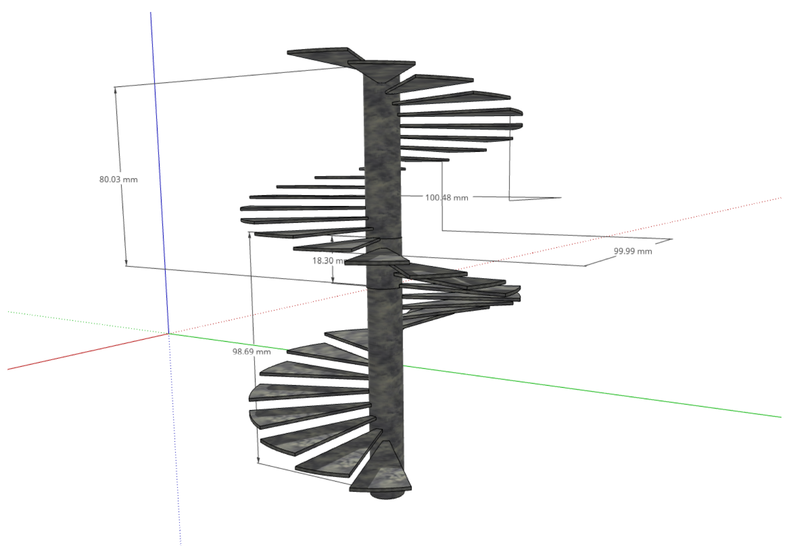

Figure 1: Conceptual Design - Spiral

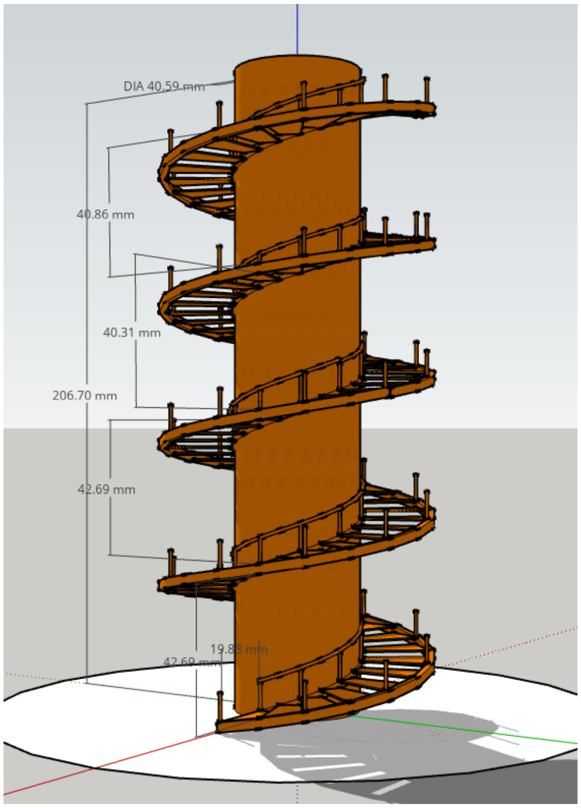

Figure 2: Detailed Design - Spiral

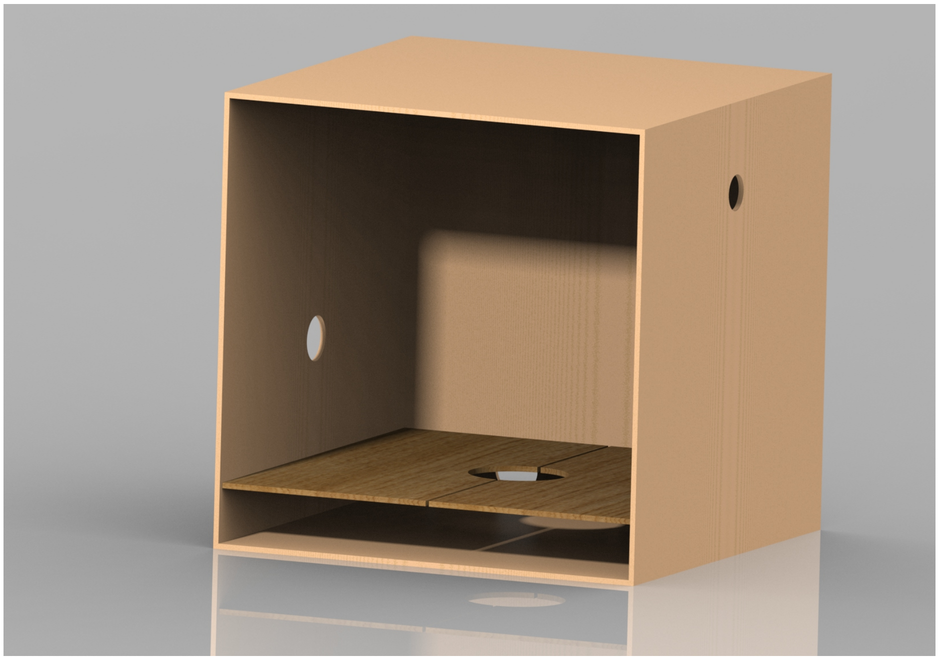

Figure 3: Detailed Design - Box

Figure 4: Detailed Design: Ramp (1)

Figure 5: Detailed Design: Ramp (2)