

University of Toronto
Faculty of Applied Science and Engineering
ASP111 & APS112
Conceptual Design Specifications (CDS)

Team #	144	Date	March 26, 2023
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Please check off which components you are submitting for your assignment.

CDS submitted as a PDF to Quercus with the following components:

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Executive Summary

The archives of the Centre for Industrial Relations and Human Resources (IRHR), located at 121 St. George St., Toronto, ON, as part of the University of Toronto, houses books and resources primarily from the 1980s. This document is designed to convey the client's want, need, gap, and scope, as well as the service environment, stakeholders, design requirements, alternative design generation, selection, and proposal.

Based on meetings with our client Mrs. Manda Vrkljan, the Librarian at the Centre for IRHR, the archives lack the means for maintaining an appropriate environment for the preservation of archival content and we believe that a means to do this is what they primarily need. The client also wants a complete threat analysis, and new more efficient spatial arrangement as well. The numerous pipes, ceiling cracks and holes, and vents, all parts of the service environment, pose a threat to the archival contents by fluctuating the environmental conditions from the ideal. The temperature currently is between 5-27°C and humidity is between 5-100% with a flooding risk of 7.5-13 cm of water. The City of Toronto, as the property is a listed and historic property, University Planning, Design & Construction, with their power to approve the project, Ontario Library Association, with its interest in archives and preservation, and the University Investors and Donors, with their funding of such projects, are all important major stakeholders in the project.

The primary function of the design is to preserve ideal content conditions for the archival content. The design should also ideally be usable for reading and processing, electrically convenient with ample outlets, make efficient use of space for storage, have content be easily accessible and have ample space to be maneuverable. The constraints shown in this document are based on the limits presented by the client during our meeting and through deeper secondary research of those in official documents, such as the Canadian Justice Laws, Ontario Building Codes, and City of Toronto Building and Construction Codes. For the design to be accepted, it must adhere to key constraints: Heating Ventilation and Air Conditions (HVAC) and pipes cannot be worked on, alterations to permanent structures should be avoided, all appropriate permits must be received before implementation of the design, the temperature must be maintained between 15°C and 25°C, humidity must be between 30% and 75%, and lighting of the room must not exceed 150 lux.

Processes such as free and structured brainstorming, blue sky thinking, morph charts, SCAMPER, and analogy were used to generate ideas which were then consolidated to form solutions. From 69 solutions we condensed down to 3 Alternative Design Solutions using an iterative process of consolidation, feasibility, multi-voting and a graphical decision matrix. The proposed conceptual design was selected from this using the Pugh method. Detailed descriptions for each are given too. The success of the design will be measured by modeling the thermal energy flow of the archive space under our design against the main objective of temperature control. We believe the "Insulated Basement" is the appropriate solution as it best meets the objectives while satisfying all the functions and remaining within the constraints. Upon measuring the success of the design and receiving approval, we will propose this design to be used for the redesign of the archival space.

1.0 Introduction

The Industrial Relations and Human Resources (IRHR) Library contains an archive room housing primarily books and other paper media dated from 1950-1980 (Appendix B). The archive room is located in the basement, accessible only by stairs, and has no windows (See Figure 1). The client, Manda Vrkljan, the librarian at the IRHR Library, has indicated concern for environmental threats to her collection and requested a redesign of the archival space accordingly (Appendix A).

The purpose of this document is to define the design space for the redesign project. This report is divided into multiple sections: the problem, the environment in which the design will operate, important impacted organizations, and the requirements for the design, documentation of the idea generation, selection process, and proposed design development process, reasoning for the proposed design and process for measuring the success of the design.

2.0 Problem Statement

Temperature, humidity and lighting pose primary threats to the IRHR Library Archival Space regarding the preservation of the archival content (Appendix A). The client wants three deliverables: a complete threat analysis (Appendix G), three solutions (1 year, 5-year and long-term), and further optimization of the spatial arrangement of the room (Appendix A).

There is currently a lack of a means of effectively regulating environmental conditions (temperature, humidity, light, and airborne particles) in the archival space. The current solution fails to maintain safe environmental conditions causing accelerated degradation of the archive contents [1]. We believe the client needs a means to control environmental conditions and protect the stored archive contents. .

Our scope will focus on controlling the environment of the room to prevent further damage to the archives. We have limited our physical scope to the room outlined in Figure 1 below (Appendix A). Our scope includes the surface of the surrounding walls, roof, and floor, along with everything inside except for the various pipes along the roof (Figures 3 and 4). Our scope is designed this way so that the primary need of the client can be addressed with a minimally invasive approach.

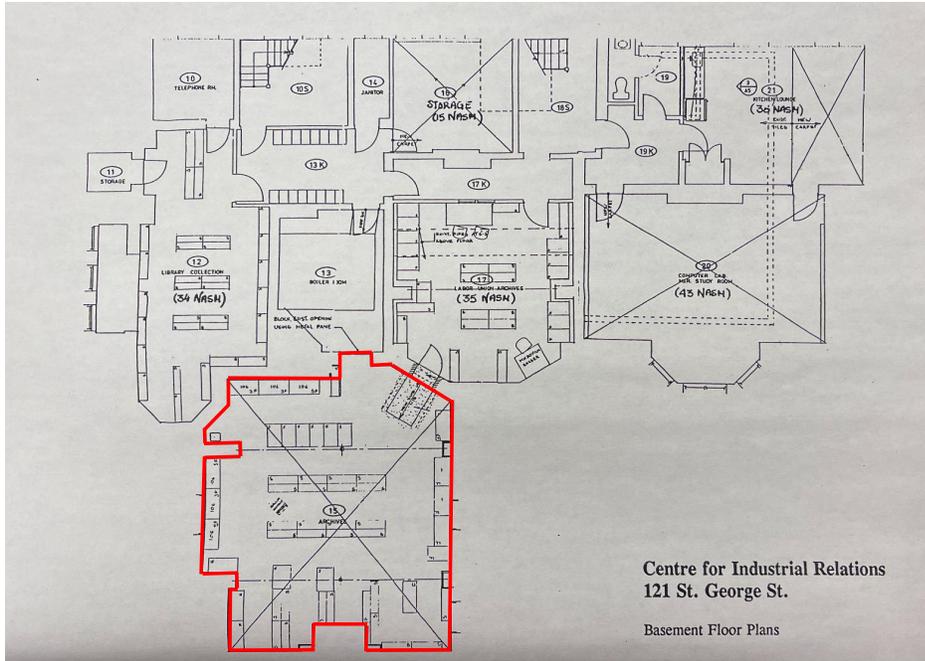


Figure 1. Annotated blueprint (Appendix B).

3.0 Service Environment

This section examines the environment our design will operate in and is divided into three sections: physical, living, and virtual. For site visit analysis, refer to Appendix B.

3.1 Physical

Refer to Appendix H to view the layout of the archive area. In addition, the physical environment of the basement is composed of the following key elements:

Table 1. Physical Elements

Element	Description
Temperature	February 6, 2023, 11:30 am: 18.29°C Estimated Range: 5-27 °C (Appendix B)
Humidity	February 6, 2023, 11:30 am: 21.1% Estimated Range: 5-100% (Appendix B)
Flooding Risk	7.5-13 cm of water (Appendix B)
Fluorescent Lights (Fig. 2)	Attached to the ceiling, estimated to be 1600-3200 lumens, assuming that it is 32W (Appendix B)
Natural gas pipeline (Fig. 3)	Several pipes carry natural gas attached to the ceiling. They are 1.7m above the floor (Appendix B).

Ventilation pipeline (Fig. 4)	Several pipes for ventilation are attached to the ceiling. They are 1.8m above the floor (Appendix B).
Ceiling cracks and holes (Fig. 5)	Holes near the corners of the basement ceiling. Water leaked through similar holes in the adjacent room (Appendix B). These holes may allow hot air to exit, decreasing the room temperature [2].



Figure 2. Fluorescent light.



Figure 3. Natural gas pipe.



Figure 4. Ventilation pipe.



Figure 5. Ceiling hole with deteriorating foundation

3.2 Living

The Library Archive Room had no evidence of living things present. The client stated that pests had not been discovered in this basement room prior to this project either (Appendix B). The only humans that have access to the room are the users (students, professors, and researchers), who will always be accompanied by IRHR Library staff members (Appendix B).

3.3 Virtual

The basement has Wi-Fi and cellular signal coverage. Through inspection, the Wi-Fi download speed was 31.84 Mbps, and the upload speed was 19.74 Mbps (Appendix B).

4.0 Stakeholders

Table 2 below lists the key stakeholders of our design project and details their influence on the design or how designs will influence each stakeholder. The key stakeholders were identified using the stakeholder analysis graph found in Diagram 7 in Appendix C.

Table 2. Key Stakeholders and Their Impact.

Stakeholders	Impact on Design
Key Stakeholders (High Interest, High Influence)	
The City of Toronto	The building is a listed protected historical property [3], thus the design must follow a minimal intervention approach to preserve the heritage according to the Ministry of Heritage and follow compliance codes (Section 5.3).
University Planning, Design & Construction	They oversee all major construction projects at the University of Toronto [4] and the archival space resides in a university building, thus the redesign will require their approval.
Ontario Library Association (OLA)	As we are preserving historical records they may have influence over the design since they are closely related to library science, archives, preservation and special collections. This means they

	may have an interest in the redesign of the archives [5].
University Investors and Donors	University investors and donors provide financial support and influence funding allocations for this redesign project through the Industrial Relations & Human Resources Trust [6]. The design must follow Capital Planning and Capital Projects Policy [7].

5.0 Detailed Requirements

Our project is to redesign the IRHR Library Archive Space. All ideas generated must achieve the primary function and abide by all constraints. Our objectives have been ranked using pairwise comparison and are ordered by importance.

5.1 Functions

See Appendix D for the processes we used to generate functions, including the Black Box Method, Functional Basis, and Functional Decomposition. See Table 3 below for the primary and secondary functions.

Table 3. Functions.

Primary Function	Secondary Functions
Protect contents of the archive	<ul style="list-style-type: none"> - Hold constant ideal thermal energy - Hold constant ideal humidity - Minimize light energy - Minimize air particulates

5.2 Objectives

Objective details and justification are in Appendix E. Given below is the table of objectives. See Appendix E for how our metrics are calculated.

Table 4. Objectives.

Objectives	Metric	Objective Goal
Temperature controlled	Absolute value of (temperature in °C - 20)	≤ 2 [8]
Humidity controlled	Absolute value of (relative humidity in % - 50)	≤ 5 [8]
Air particulate controlled	Level of Filtration (%)	≥ 60 [1]

Light controlled	Average Lux (lx)	≤ 100 [9]
Quick to implement	Week(s) to implement	≤ 1
Maximize storage space	Storage space area (m ²)	≥ 21.094 (Appendix H)
Maneuverable	Width of aisles (cm)	≥ 106.7 [11]
Usable for reading and processing	Desk/working area (m ²)	≥ 1.12 1.52 m by 0.68 m desk space (Appendix B)
Accessible	Required arms reach (cm)	≤ 84 [10]
Electrically convenient	Number of available plugs	≥ 8 (Appendix B)

5.3 Constraints

Listed below are the criteria that the chosen design must fulfill to conform to the government codes and regulations, as well as to meet the client's requirements. Appendix F provides further details regarding the rationale for these constraints.

Table 5. List of Constraints, Metric and Limit

	Constraint	Metric	Limit
1	Must maintain the existing HVAC and ventilation systems as per subsection 2.24 of the Canadian Justice Laws [12]	Binary: yes/no	Yes
2	Must avoid alterations to permanent structures within the building as seen in subsection 2.27 of the Canadian Justice Laws [12]	Binary: yes/no	Yes
3	Must not modify any of the pipes per the client's requests [8]	Binary: yes/no	Yes
4	Must adhere to the Ontario Building Codes Section 1.7 of	Binary: yes/no	Yes

	Division C [13]		
5	Must comply with the City of Toronto Building Code Act [14]	Binary: yes/no	Yes
6	Must be contained within the scoped area (Section 3.1)	Binary: yes/no	Yes
7	Must maintain relative humidity between 30% and 75% [8]	Binary: yes/no	Yes
8	Illumination must not exceed 150 average lux [8]	Binary: yes/no	Yes
9	Must maintain temperature between 15°C and 25°C [15]	Binary: yes/no	Yes

6.0 Alternative Design Generation, Selection and Descriptions

This section includes the process of generating and reducing ideas using a variety of methods, and then the descriptions of our top three designs.

6.1 Idea Generation

We utilized free and structured brainstorming techniques to generate ideas for our four secondary functions. The ideas were then put into a morph chart to generate full ideas. SCAMPER was then used in addition to blue sky thinking, random stimulation, and analogy to generate more ideas. We then performed a feasibility check and consolidated our ideas into a table and were left with 69 feasible designs. See Appendix I, J, and K for the different stages and list of ideas.

6.2 Alternative Design Selection

The three solutions were selected through feasibility checks, consolidation, multi-voting and a graphical decision matrix. Two iterations of multi-voting were implemented to condense the list of 69 solutions to 10. A graphical decision chart was then used to judge the 10 designs against their performance in controlling temperature and humidity, our two main objectives. The top 3 performers have been presented below as the Alternative Designs. See Appendix K for our selection process in detail.

6.3 Alternative Design Descriptions

The following section describes our top three designs and how well they meet our objectives. All designs are within the basement room and no modifications are made to permanent structures, existing HVAC, or pipes and are only bringing in removable equipment allowing them to meet the first six constraints. See Appendix N for justification on the results provided by each design's objective table.

6.3.1 Environmentally Controlled Cabinets (Design 1)

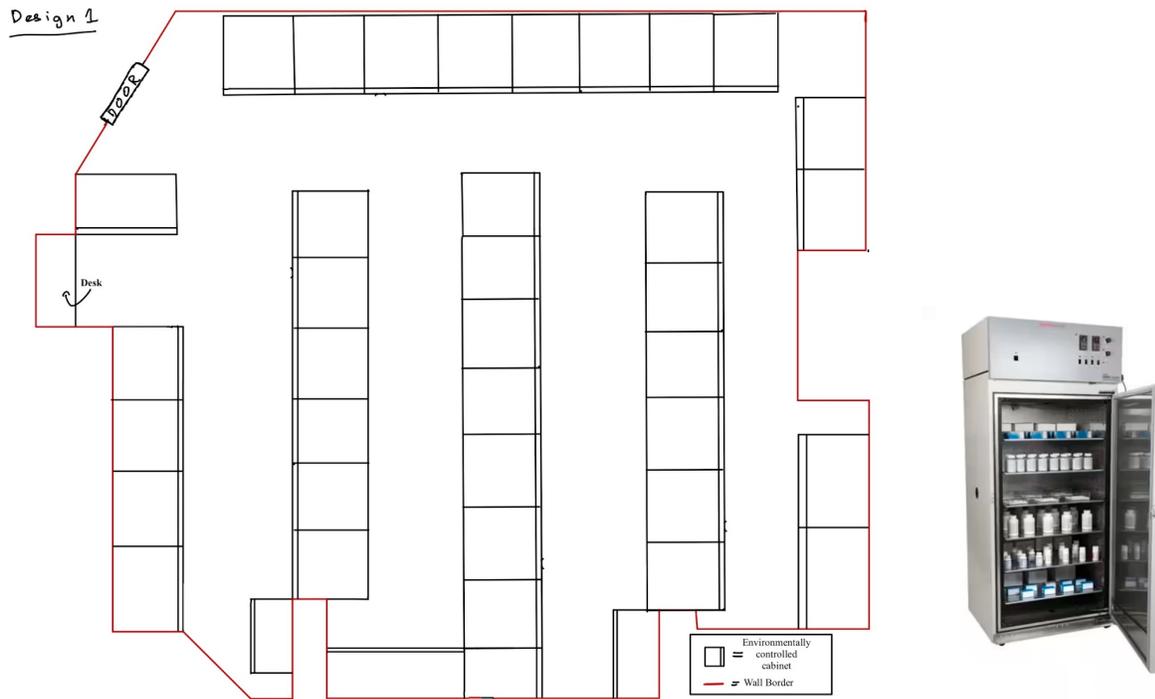


Figure 6. Layout of Design 1 (left) and image of COTS cabinet (right) taken from [34].

The main feature of this design is the use of 40 environmentally controlled cabinets, which were chosen as they control internal temperature, humidity, light, and air particulates using built-in environmental control functions such as internal temperature and humidity control devices, automatic lighting, and HEPA air filters. To provide electrical energy, two plugs will be installed on each wall and the ceiling to power the cabinets. A desk will also be added as a workspace. Due to the enclosures taking up space, maneuverability was sacrificed in order to maintain storage space.

Table 6. Objectives for Design 1.

Objectives	Metric	Objective Goal	Result
Temperature controlled	Absolute value of (temperature in °C - 20)	≤ 2	0 (Meets 8th constraint)
Humidity controlled	Absolute value of (relative humidity in % - 50)	≤ 5	0 (Meets 6th constraint)
Air particulate controlled	Level of Filtration (%)	≥ 60	99.97
Light controlled	Average Lux (lx)	≤ 100	13.4 (Meets 7th

			constraint)
Quick to implement	Week(s) to implement	≤ 1	16
Maximize storage space	Storage space area (m ²)	≥ 21.094	21.2
Maneuverable	Width of aisles (cm)	≥ 106.7	86
Usable for reading and processing	Desk/working area (m ²)	≥ 1.12	1.12
Accessible	Required arms reach (cm)	≤ 84	68.6
Electrically convenient	Number of available plugs	≥ 8	8

6.3.2 Insulated Basement (Design 2)

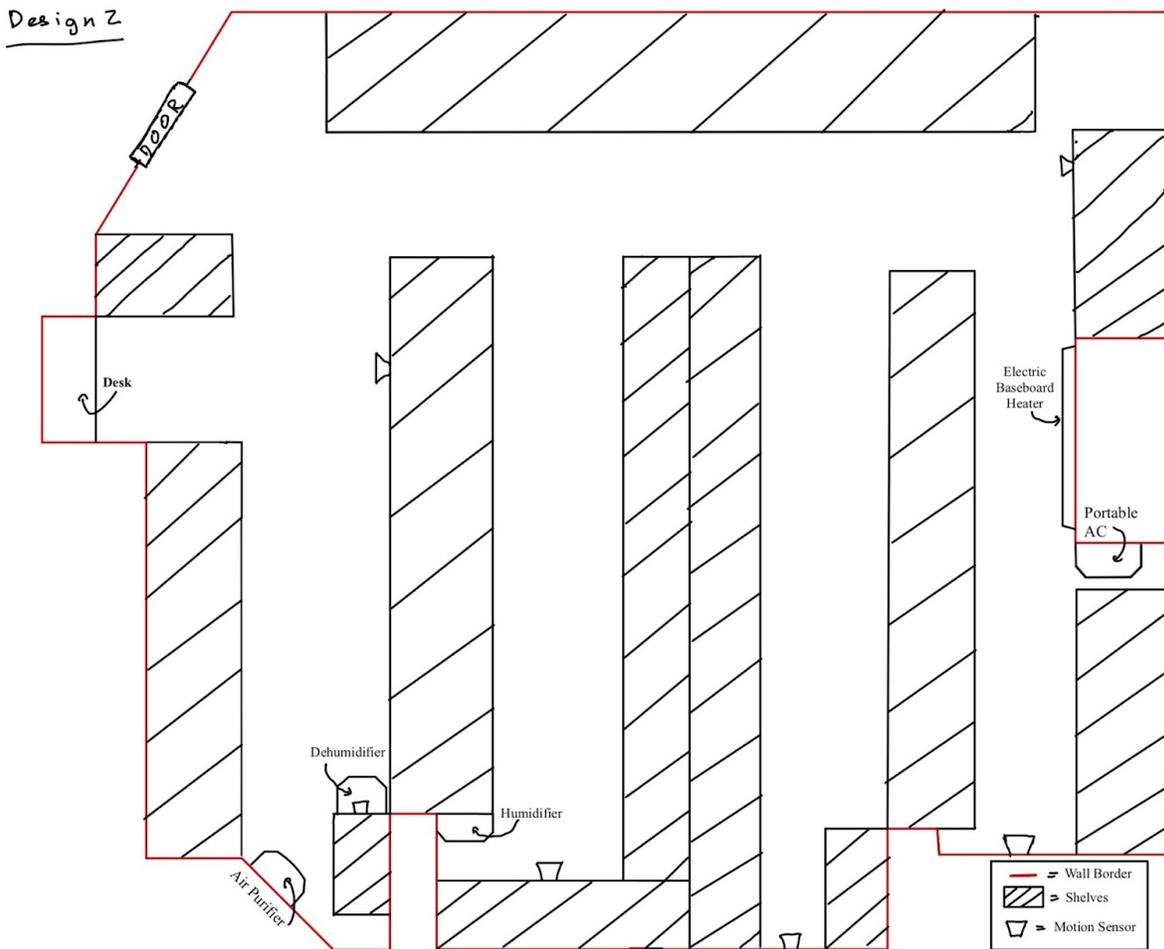


Figure 7. Design 2 layout.

The key feature of this design is the application of rockwool insulation to the surfaces of the walls to increase temperature control efficiency. Temperature is regulated with a portable air-conditioner and an electric baseboard heater. A portable humidifier and dehumidifier control the humidity. Motion sensors will light only the areas users are in to reduce archive light exposure, and a HEPA air filter reduces air particulates. To provide electrical energy, two plugs will be installed on each wall in addition to the plugs required for appliances. In order to accommodate the desk addition, the design utilizes an increased shelf depth, however still exceeding our accessibility objective.

Table 7. Objectives for Design 2

Objectives	Metric	Objective Goal	Result
Temperature controlled	Absolute value of (temperature in °C - 20)	≤ 2	0 (Meets 8th constraint)

Humidity controlled	Absolute value of (relative humidity in % - 50)	≤ 5	0 (Meets 6th constraint)
Air particulate controlled	Level of Filtration (%)	≥ 60	99.97
Light controlled	Average Lux (lx)	≤ 100	17.9 (Meets 7th constraint)
Quick to implement	Week(s) to implement	≤ 1	3.6
Maximize storage space	Storage space area (m ²)	≥ 21.094	22
Maneuverable	Width of aisles (cm)	≥ 106.7	93
Usable for reading and processing	Desk/working area (m ²)	≥ 1.12	1.12
Accessible	Required arms reach (cm)	≤ 84	38
Electrically convenient	Number of available plugs	≥ 8	8

6.3.3 Basic Portable HVAC (Design 3)

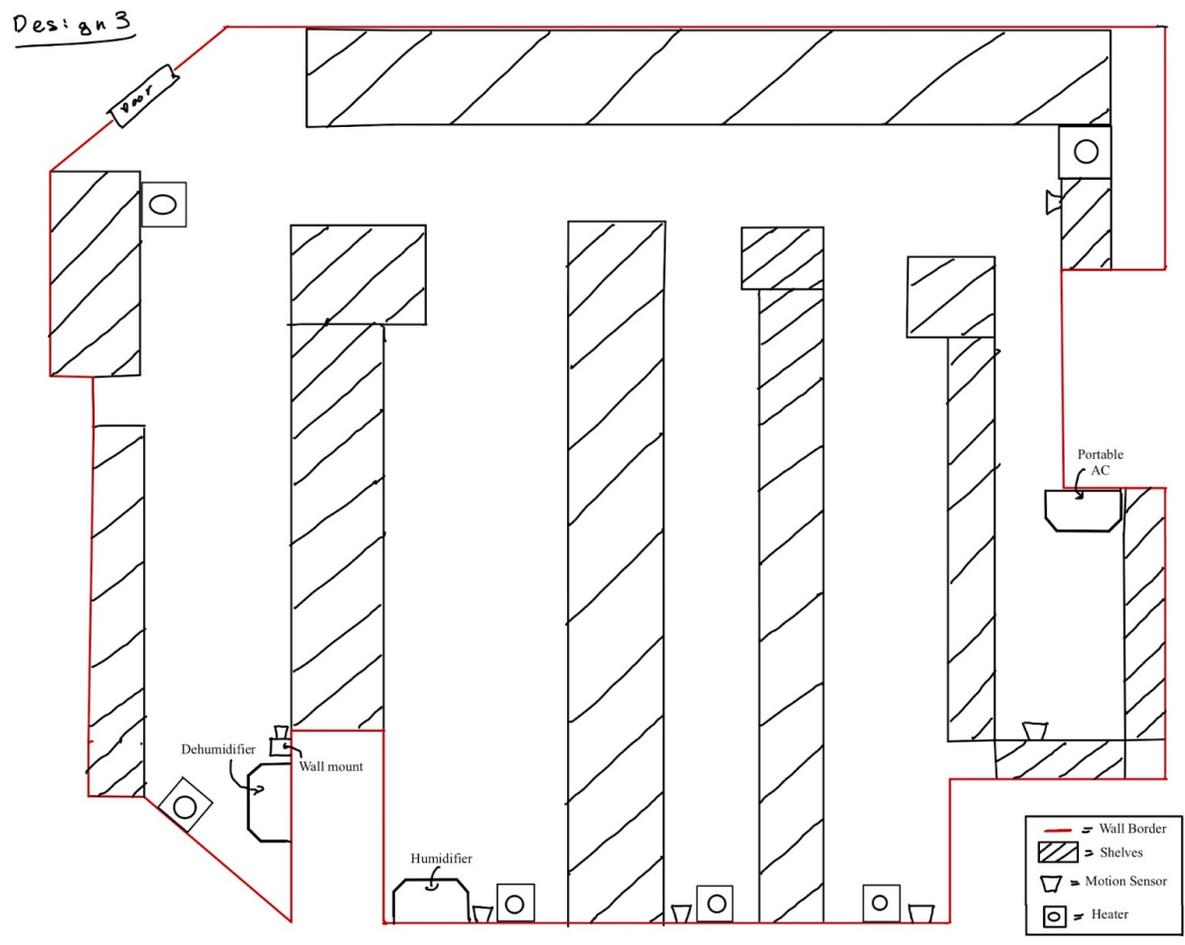


Figure 8. Design 3 layout.

The key feature of this design is the application of basic portable HVAC subunits to maintain the room’s environment. The room temperature will be regulated by two air conditioners and six heaters. A humidifier and dehumidifier will control the humidity. Users will use a lantern when accessing the space to provide light only surrounding the user. A HEPA-filtered hand-held vacuum will manage air particulates. To provide electrical energy, a series of extension cords and surge protectors will be run in from the adjacent room. In order to meet the high-temperature control demands of the room, we were required to compromise on maneuverability of the design.

Table 8. Objectives for Design 3

Objectives	Metric	Objective Goal	Result
Temperature controlled	Absolute value of (temperature in °C - 20)	≤ 2	0 (Meets 8th constraint)
Humidity controlled	Absolute value of (relative humidity in % -	≤ 5	0 (Meets 6th constraint)

	50)		
Air particulate controlled	Level of Filtration (%)	≥ 60	99.97
Light controlled	Average Lux (lx)	≤ 100	8.9 (Meets 7th constraint)
Quick to implement	Week(s) to implement	≤ 1	1
Maximize storage space	Storage space area (m ²)	≥ 21.094	21.094
Maneuverable	Width of aisles (cm)	≥ 106.7	68.8
Usable for reading and processing	Desk/working area (m ²)	≥ 1.12	1.12
Accessible	Required arms reach (cm)	≤ 84	30
Electrically convenient	Number of available plugs	≥ 8	8

7.0 Proposed Conceptual Design

Table 9. Pugh Chart

Objectives	Datum	1. Ventilated Boxes	2. Insulation Basement	3. Basic Portable HVAC
Temperature controlled	S	2	2	2
Humidity controlled	S	2	2	2
Air particulate controlled	S	2	2	2
Light controlled	S	2	2	2
Quick to implement	S	-2	-1	0
Maximize	S	0	0	0

storage space				
Maneuverable	S	-1	0	-2
Usable for reading and processing	S	2	2	2
Accessible	S	2	2	2
Electrically convenient	S	2	2	2
Total Score	S	9	11	10

The final proposed design is the Insulated Basement, determined through the Pugh Method whereby 3 alternative designs are compared to the current solution (Datum), regarding how well they meet our objectives.

Table 9 above demonstrates that all three alternative designs were close as they all maintain environmental control very well. As evident from the section 6.3 tables, all three designs have a temperature and humidity deviation of 0 and the highest air filtration of 99.97%. In terms of light control, all three designs are within the range of 8.9 to 17.9 lux which is greatly below 100 lux.

However, the differences and tradeoffs made between the designs for the other objectives are what determined our proposed solution. Design 3 has an advantage as it is the quickest to implement of the 3 designs, however, it sacrifices maneuverability due to the high number of temperature control devices and running of extension cords. Conversely, Design 1 takes the longest to implement due to its custom-design nature. Thus, our pugh chart determined Design 2 (Insulated Basement) was the best compromise between all aspects of the design.

8.0 Measures of Success

Our planned measure of success is to model the thermal energy inflows and outflows of the room to determine if our proposed design can maintain the desired 20 °C. The following plan outlines the steps required to do this:

Week 1: Equipment Acquisition

3/29-31 Sonnet will acquire a thermal imaging camera from UofT Growth Facilities [16]
 3/31 Nafew sends an email to the client to schedule a fourth site visit on 4/4

Week 2: Assessment

4/4 The team revisits the archival room to

- Measure surface area and thickness of walls
- Identify specific wall materials
- Locate locations of additional heat loss using the thermal camera [17]
- Measure temperature differential between inside and outside

- 4/4 Nafew calculates existing wall structure R-value
- 4/5 Nafew calculates new R-value for the room including foam insulation [34]
- 4/5 Khadija using outdoor historical temperature data, calculates 99% high and 1% low-temperature differentials

Week 3: Modeling

- 4/10-12 Matthew and William, using data collected from the site visit, as well as calculations from last week, model the archive using thermal energy flow [18] to determine the heating and cooling energy required to maintain the desired 20 °C
- 4/13 Issa, using these requirements and product specifications for generic commercial off the shelf products, determines if the proposed design can maintain a constant 20 °C

9.0 Conclusion

This document addresses the gap and needs of the client and the archival space at the Centre of IRHR based on their wants. Our client, Manda Vrkljan, needs a means of controlling and regulating the environment to protect the archives. Through site visits, the client meeting, research and documents received from the client, the service environment, stakeholders and constraints of the design were defined. Through further meetings, the primary function (to preserve ideal content conditions), secondary functions (holding constant ideal thermal energy and humidity, removing light energy and removing air particulates), and objectives were outlined. The “Insulated Basement” design is our proposed design. Foam-insulated walls, portable AC and electric baseboard heater controls temperature. Portable humidifier and dehumidifier control the humidity. Motion sensors control lighting. HEPA air filters will reduce air particulates. To measure the success of the design against our prioritized objective of temperature control, we will be modelling the thermal energy flow of the archive space under our design.

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Appendix A: Client Statement Analysis

The Centre for Industrial Relations and Human Resources in [sic] located in a historic Victorian house on St. George Street. The allotted archival space is housed in a below ground windowless room, which is a great basis for the storage of paper and media. However, temperature and humidity conditions, an open sewer drain, overhead pipes, exposed exterior brick walls, and poor ventilation are ongoing threats to the collection. From this project, we hope to receive a report that outlines all possible threats to the collection from the space, how to maintain appropriate environmental conditions within the space, and recommendations on the best physical arrangement for the collection in order to maximize the available space [19].

Deliverable:

Report that outlines all possible threats to the collection from the space, how to maintain appropriate environmental conditions within the space, and recommendations on the best physical arrangement for the collection in order to maximize the available space

What information we will want:

- Detailed dimensions
- Detailed photos of the entire space, especially at threat points
- Catalog of the archival collection
- Notes on:
 - Threat points
 - HVAC components
 - Current environmental control points
 - Current damage to collection

Problem Statement Brainstorming:

Want:

- threat analysis
- 3 solutions, 1 year, 5-year, long term
- location optimization plan

Need:

- 1 year stop-gap solution to protect archives from immediate damage.

Gap:

- there is a lack of a means to regulate the temperature, humidity, and dust of the archival space

Scope:

- No touching pipes
- No touching anything that is permanently attached to the building
 - lack of qualification
 - HVAC

- health
- minimally intervention approach
 - preserve heritage
- excessive regulations, time constraint

Appendix B: Client Meeting Notes and Site Visit



Figure 9: Measure of temperature and humidity.

Temperature Estimations:

18.29 °C inside archive February 6th, 2023, 11:30 am (Fig. 9)

It was -3 °C outside in Toronto on the same day and time [20].

Finding the difference in indoor and outdoor temperatures will give us a rough estimate of how well the room can heat its environment. The difference in temperature is equal to ~21 °C. The 1% low outdoor temperature for Toronto is -16.1 °C [21].

We can add 21 °C to -16 °C to get 5 °C as the low-temperature range for the room.

To calculate the high-temperature range, we can use the indoor temperature estimation formula for non-air-conditioned rooms provided by Firstgreen Consulting [22].

99% high outdoor temperature for Toronto is 26.8 °C [21]

Indoor Temperature = $(0.54 \times \text{outdoor temperature}) + 12.83 = (0.54)(26.8) + 12.83 = 27 \text{ °C}$

Using these rough estimation methods, we can estimate that our design must operate in the temperature range 5-27 °C.

Humidity Estimations:

77% outdoor humidity average on February 6th [23]

The difference in indoor and outdoor temperature was 21 °C

21.1% inside the archive on February 6th, 2023, 11:30 am (Fig. 9)

The difference in humidity is about 56%. Thus we can estimate that the humidity drops 2.7% for

each degree lower the archive gets. This means that at the lowest estimated temperature (5 °C), the humidity is estimated to be $21\% - 13 \times 2.7\% =$ well below 0%. Although we know this isn't physically possible, we will use 5% as an estimated low for the range of humidity our design must operate in.

Due to our knowledge, the flooding has occurred in the room, we can estimate that the upper range for relative humidity is 100%.

Therefore, using these rough estimation methods, we can estimate that our design must operate in the humidity range of 5-100%.

During an interview with our team on February 6th, 2023, Librarian Manda Vrkljan communicated the following information [24]:

- Low flooding (<5") has occurred before in the archive room
- Natural gas boiler empties into the archive room, causing petroleum smells
- No air conditioning
- Walls are made of brick
- Ideal conditions are 20-22 °C and 40-50% humidity
- It is hot and humid in the summer, and dry in the winter
- No pest issues
- No regular dusting occurs
- No adjustments to existing pipes along the roof
- Archive content is primarily dated from 1950-1980
- Would like a table in the archive room for working space
- Adjacent room had flooding from the roof this winter, ruining an entire shelf of books
- User access will always occur with a IRHR Library staff member present

Although an exact figure was not given, we can assume that less than 5 inches (12.7 cm) of flooding likely refers to flooding between the range of 3-5 inches (7.62 cm - 12.7 cm) of water.

Ceiling pipes height estimations:

Natural gas pipeline: One of the members on the team fit almost perfectly under this pipeline, and their height was 1.7m. Thus, the height of this pipeline should be around 1.7m

Ventilation pipeline: One of the members on the team fit almost perfectly under this pipeline, and their height was 1.8m. Thus, the height of this pipeline should be around 1.8m

Fluorescent light luminance estimation:

A fluorescent light emits 50-100 lumens per watt [25], and the average fluorescent light used in households is 32 watts [26]. Therefore the luminescence of the light should be around:

$$32 \text{ watts} \times (50 \text{ to } 100 \text{ lumens/watt}) = 1600 \text{ to } 3200 \text{ lumens}$$

Our client meeting took place on Monday, February 6th, from 11am-12pm. Our first site visit occurred during the same time. Our second site visit took place on Monday, February 13th from 11-12pm.

No non-human organisms were observed during our site visits.

During the client meeting, Librarian Manda Vrkljan also communicated regarding workspace, storage space and electrical outlets:

- Workspace of a normal sized desk of 152cm by 68cm (width x length) is necessary to process archives inside the archival space.
- Manda has recently taken 15 more boxes of archival material from a library that is currently shutting down and now needs more storage space. She wants a storage efficient space to maximize the number of archives that she can store.
- In order for the workspace to be feasible, Manda also mentioned the need for power plugs/outlets so that other librarians can plug their electronic device and work for however long with ease and without worry of their device losing power.

Table 10. Objects and Current Solutions Observed During Site Visits

Object	Location Note	Purpose/Concern	Design Note
Overhead Piping	Along the roof and walls of the room	Carry mass throughout house/library	Add pipes to service environment
Reflective Tape	On piping	Improves visibility of pipes to decrease accidental head injury	Include safety as an objective
Ceiling Holes and Cracks	Along the roof	Possible water intrusion site	Add flooding to service environment
Brown Staining	Along the walls, pipes, and roof	Indication of moisture and water leak	Add high humidity to service environment
Vents	There are two vents in the basement, one at the south-west corner of the basement blowing in fresh air from outside and one in the north-east	bring in air from adjacent room	Add to service environment

	corner blowing out air.		
Metal Shelves	Interior of the room	Hold and organize archive content	Current solution
File Boxes	On/inside metal shelves	Hold and organize loose paper and folders	Current solution
Bookends (stands)	On/inside metal shelves	Prevent books from tipping over	Current solution
Filing Cabinets	Interior of the room	Hold and organize loose paper and folders	Current solution
Row/Bar Lights	Spread across the roof of the room	Provide light for visibility of users inside	Include provide visibility in objective
Rolling Chair	In between metal shelves in an aisle	Resting area for users. Support users weight	Current solution
Stool	In between metal shelves in an aisle	Support users' weight, lifting users to increased height.	Include accessibility in the objectives
Temperature / Humidity Sensor	Attached to metal shelf at head height	Log data	Include data in the service environment.
Fireplace	On the wall across from the entrance	No purpose anymore	Included in the service environment.
Plastic Covers	Covering fireplace opening	Separate fireplace and archive air environments	Current solution
Electrical Wires	Along roof of room	Carry electrical energy around the house	Included in the service environment.
Fluorescent lights	On the roof of the room	Provide lighting to the archival space	Included in the service environment.
Basement floor drain	There is a floor drain at the center of the	Drains excess water from the basement	Add flooding to the service environment.

	basement.	[27].	
Drain pipeline	There are 2 visible pipes that are connected to the drainage system [27], one near the entrance and one around the south-west side of the basement (with respect to the entrance being south).	The pipe near the entrance has rust.	Included in the service environment.

The following Wi-Fi speed test was conducted during our second site visit (Figure 10).

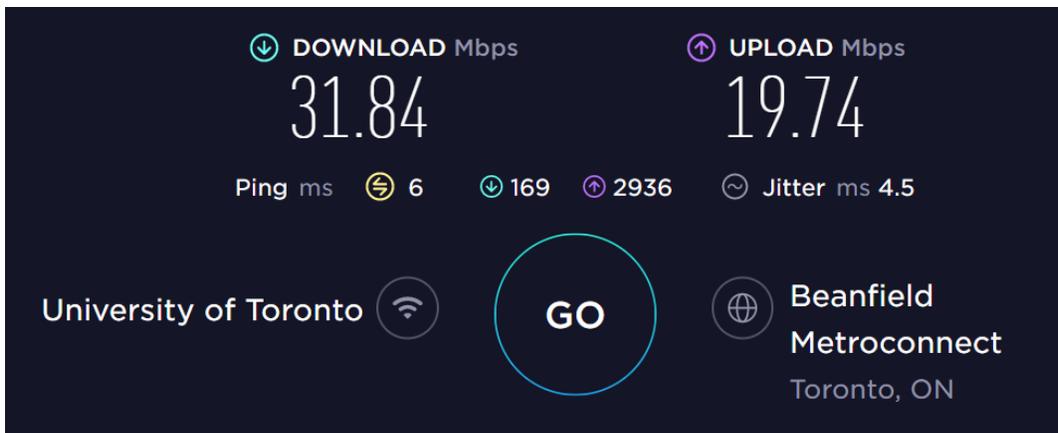


Figure 10: Speedtest results taken in basement through Ookla [28]

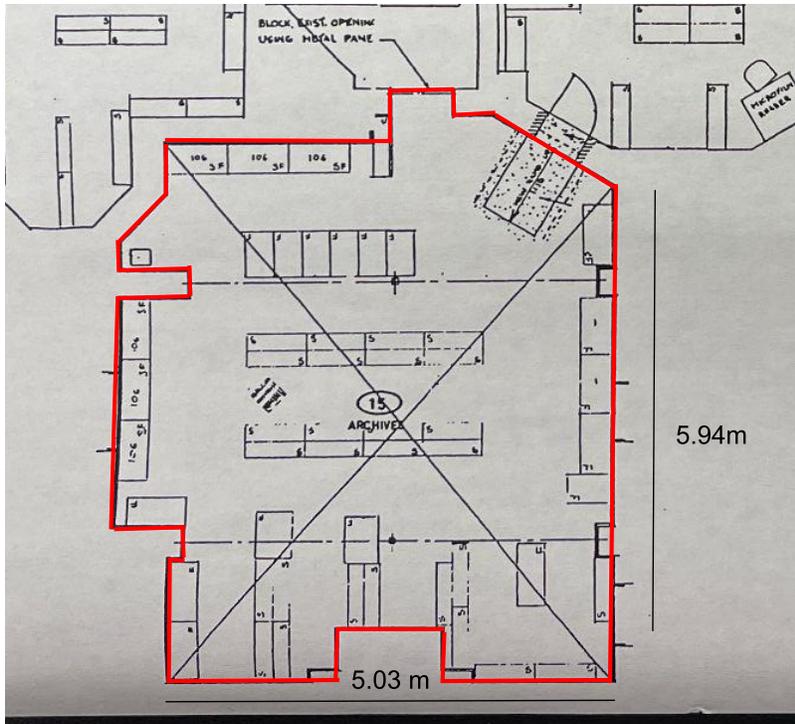


Figure 11: Map outlining measurements of the room

Using measurements from our site visit and the fact that the archive is a near rectangular shape, we can estimate the total area to be roughly 30 m^2 . The height of the archive not including the pipes was approximately 2.2m

Appendix C: Stakeholders Generation

This section which includes Figure 12 and Table 5 list potential stakeholders to the project.

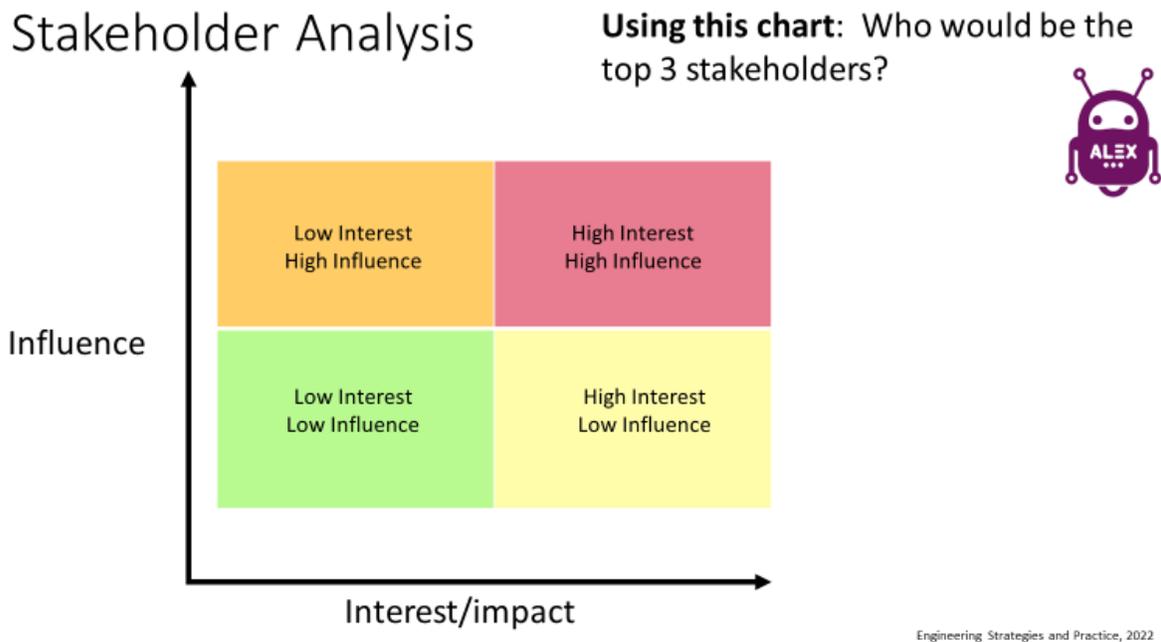


Figure 12. Influence and Interest chart of Stakeholder Analysis [29]

Table 11. Stakeholder Generation Table.

Potential Stakeholders
The City of Toronto
University Planning, Design & Construction, the University of Toronto
Ontario Library Association (OLA)
University Investors and Donors
Local Communities
Local Businesses
Indigenous Group
UofT Student Union
Library architects and designers

Appendix D: Function Generation

Drawing from the problem statement, the client's need is a design that controls environment conditions and can create an appropriate space for storing the archive contents.

To determine the primary function, we brainstormed functional requirements an archival space may have, and determined which one/ones would cause the design to fail if they were not included.

The design must protect/preserve the contents of the archive. If the design doesn't protect the archive contents, then it would fail as an archive. The contents must be accessible to view. If the information stored here is unable to be viewed, then it is not an archive?

Store, deposit, place

Support, maintain, secure, steady, hold constant

Transport, retrieve

Mass (archive contents)

Possible Primary Functions:

Store archive contents

Hold constant the conditions of the archive content material → Preserve ideal content conditions

Retrieve the archive's contents information

Protect contents of the archive (mass)

First, we use the black box method (see Table 12) to generate basic mass, energy, and information flows.

Table 12. Black Box Method

Inputs		Outputs
Mass	→ Design →	Mass
<ul style="list-style-type: none"> - Students - Professors and Librarians - Campus Staff - Books - Paper files - Tape drives 		<ul style="list-style-type: none"> - Students - Professors and Librarians - Campus Staff - Books - Paper files - Tape drives
Energy		Energy
<ul style="list-style-type: none"> - Electrical - Mechanical - Thermal 		<ul style="list-style-type: none"> - Electrical - Mechanical - Wind - Thermal - Light
Information		Information
<ul style="list-style-type: none"> - Temperature - Humidity 		<ul style="list-style-type: none"> - Item location - Temperature

<ul style="list-style-type: none"> - Person wishing to enter or exit - Item information/description 		<ul style="list-style-type: none"> - Humidity - Collection safety status
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We then performed Functional Basis Analysis on existing/current solutions (See Table 13).

Table 13. Functional Basis Analysis on Current and Existing Solutions

Current (Implied) Solution	Functional Basis
Overhead Piping	Transport mass.
Reflective Tape	Indicate information.
Vents	Extract mass.
Metal Shelves	Stores mass. It holds items on/inside of them.
File Boxes	Stores mass. It holds items inside of them.
Bookends (stands)	Hold constant mass. It holds books, preventing them from leaning over on the edge of stacks.
Filing Cabinets	Stores mass. It holds items inside of them.
Row/Bar Lights	Transform energy.
Rolling Chair	Support mass.
Stool	Support mass.
Temperature / Humidity Sensor	Detect information.
Fireplace	Transform energy
Plastic Covers	Separate energy
Electrical Wires	Transport energy.

Lastly, we used Functional Decomposition to help us narrow down our primary and secondary functions (See Figure 13).

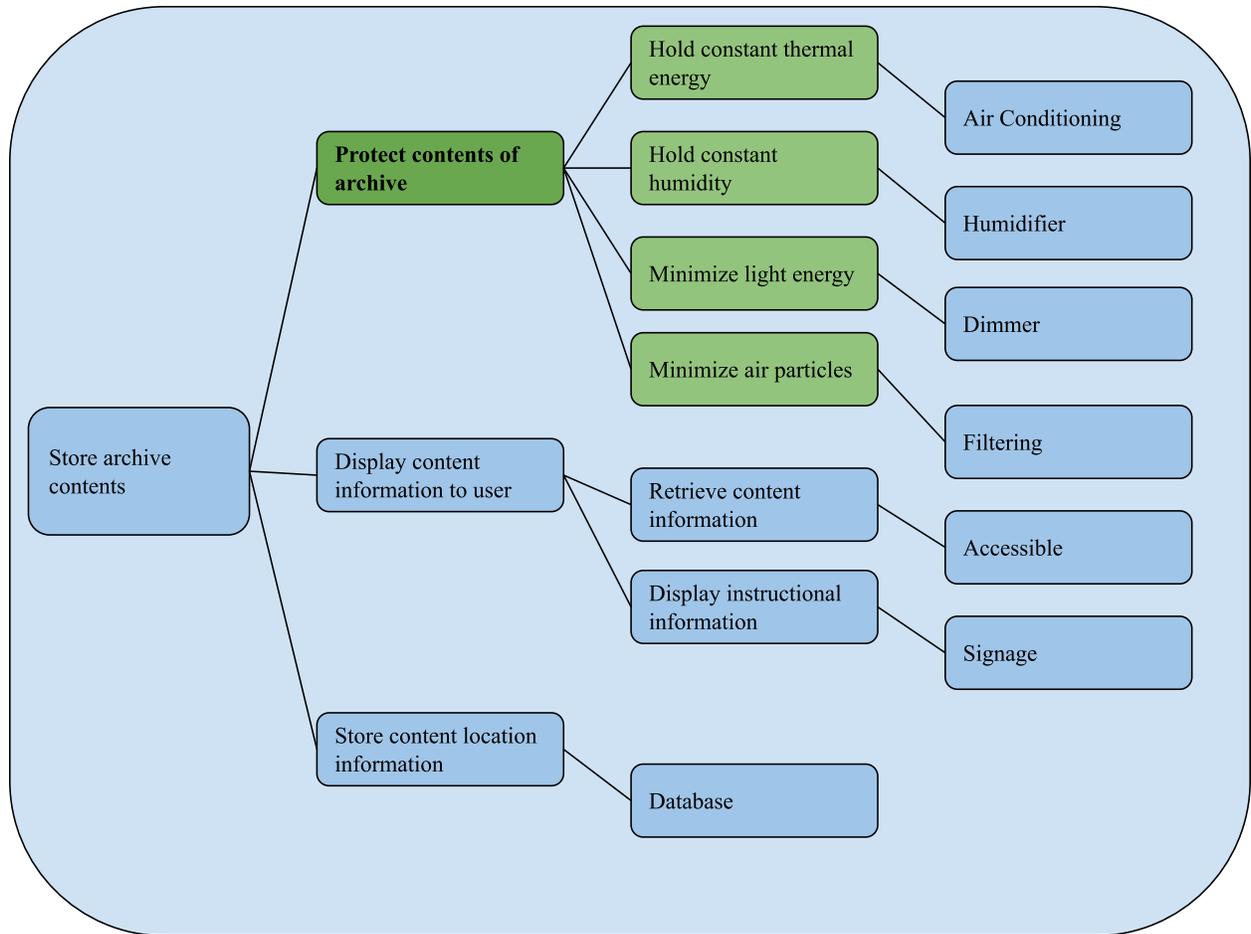


Figure 13. Functional Decomposition.

Appendix E: Objectives Generation

This section includes how we brainstormed our objectives, our objectives and their justification, and how we ranked our objectives in terms of importance.

We used a How-why tree to help us brainstorm possible objectives for our design (See Figure 14).

Figure 14. How-why tree

- ← Why How →
- Protective
 - Prevent damage to books/content
 - control environment
 - temperature
 - humidity
 - light
 - particles
 - repel physical damage

- durable
 - withstand force
 - maintain orientation
- Space Efficient
 - maximize storage volume
 - minimize free space
- Usable
 - Be able to retrieve information
 - reaching distance
 - the adequate area around
 - Be able to display information
 - work area
 - electrical plugs
 - Be able to input content
 - work area

The following Table 14 is our objective table from the main text with an additional justification column added.

Table 14. Objectives Table With Justification

Objectives	Metric	Objective Goal	Justification of Objective
Temperature controlled	Absolute value of (temperature in °C - 20)	≤ 2 [8]	Current temperature conditions are threats to the archives (Appendix A)
Humidity controlled	Absolute value of (relative humidity in % - 50)	≤ 5 [8]	Current humidity conditions are threats to the archives (Appendix A)
Air particulate controlled	Level of Filtration (%)	≥ 60 [1]	Client has indicated no dust prevention methods are in place (Appendix B)
Light controlled	Average Lux (lx)	≤ 100 [9]	Client wants alternative to current lighting in the archival space as the current lights are damaging to paper media (Appendix B)
Quick to implement	Week(s) to implement	≤ 1	Client needs to mitigate threats to archival space ideally as soon as possible to protect her archives from any possible damages in the near future (Appendix A).

Maximize storage space	Storage space area (m ²)	≥ 21.094 (Appendix H)	Client needs more storage space as she recently took in 15 boxes of new archives (Appendix B) and “maximize the available space” (Appendix A)
Maneuverable	Width of aisle (cm)	≥ 106.7 [11]	Client wants feasible movement within archival space (Appendix B)
Usable for reading and processing	Desk/working area (m ²)	≥ 1.12 1.52 m by 0.68 m desk space (Appendix B)	Client needs a working space to process archives (Appendix B)
Accessible	Required arms reach (cm)	≤ 84 [10]	Feasibility of accessing archives (Appendix B)
Electrically convenient	Number of available plugs	≥ 8 (Appendix B)	Outlets are needed for an ideal workspace so 1 outlet panel for each wall ensures convenience (Appendix B)

For the temperature and humidity objective metrics, we are measuring the difference in the objective values, meaning for each objective we are considering the greatest absolute value difference away from a desired/ideal temperature or humidity (either higher or lower). The value of the variation/deviation from the ideal temperature or humidity is our objective goal.

Table 16 shows our list of objectives ranked, and Table 15 shows how pairwise comparison was used to rank our objectives. Figure 14 shows a how-why tree, which we used to brainstorm objectives. The higher the total number read horizontally (by row), the higher its priority as an objective which is illustrated on a (1-10) scale in Table 16. 1 being the highest priority and 10 being the lowest.

Table 15. Pairwise Comparison Chart

	Temperature Controlled	Humidity Controlled	Usable for reading and processing	Light Controlled	Maximize storage space	Accessible	Maneuverable	Electrically convenient	Air particulate controlled	Quick to Implement	Total
Temperature Controlled	0	1	1	1	1	1	1	1	1	1	9
Humidity Controlled	0	0	1	1	1	1	1	1	1	1	8
Usable for reading and processing	0	0	0	0	0	1	0	1	0	0	2
Light Controlled	0	0	1	0	1	1	1	1	0	1	6
Maximize storage space	0	0	1	0	0	1	1	1	0	0	4
Accessible	0	0	0	0	0	0	0	1	0	0	1
Maneuverable	0	0	1	0	0	1	0	1	0	0	3
Electrically convenient	0	0	0	0	0	0	0	0	0	0	0
Air particulate controlled	0	0	1	1	1	1	1	1	0	1	7
Quick to Implement	0	0	1	0	1	1	1	1	0	0	5

Table 16. Ranking of Objectives based on Pairwise Comparison Chart

Priority <i>(1-10) high to low</i>	Objectives
1	Temperature controlled
2	Humidity controlled
3	Air particulate controlled
4	Light controlled
5	Quick to Implement
6	Maximize storage space
7	Maneuverable
8	Usable for reading and processing
9	Accessible
10	Electrically convenient

Appendix F: Constraints Research

The Canadian Government's website under the Justice Laws sections states the following about HVAC Systems:

- "2.24 (1) Every employer shall appoint a qualified person to set out, in writing, instructions for the operation, inspection, testing, cleaning and maintenance of an HVAC system and the calibration of probes or sensors on which the system relies. In writing the instructions, the qualified person shall take into account CSA Guideline Z204-94, entitled Guideline for Managing Air Quality in Office Buildings, dated June 1994." [11]
- "2.27 (1) Every employer shall develop, or appoint a qualified person to develop, a procedure for investigating situations in which the health or safety of an employee in the workplace is or may be endangered by the air quality." [11]

Therefore, this design will not alter any component of the HVAC systems or permanent structures of the buildings.

The design must also comply with the Ontario Building Codes for buildings that are being renovated by:

- Working with the municipality in order to:
 - "setting fees for building permits
 - reviewing and issuing building permits
 - inspecting sites for compliance during construction
 - issuing stop work and compliance orders." [14]

As for the City of Toronto Building Code Act, this design must not violate any of the seventeen conditions listed on their website [15]. Below is a list of all the relevant components of the code:

- "Construct an addition to an existing building, such as
 - second or third story additions
 - attached garages, carports
 - sunrooms
 - solariums, porches, decks
- Make structural or material alterations, such as
 - adding or removing walls (i.e., changing room sizes and/or uses)
 - new windows or doors where there were none before
 - enlarging or relocating existing windows or doors
 - enclosing an existing deck, porch or patio of any size
- Construct a shed with an area of 15 square meters (161 square feet) or more.
 - Note: Sheds under 15 square metres in area, do not need a building permit. See "When is a Building Permit not required?" below for exceptions to this rule
- Construct an accessory structure larger than 10 square meters (107 square feet) in area, such as
 - Detached Garage
 - Workshop
 - Carport
 - Pool house or cabana

- *Note: If you are constructing an accessory structure and it is attached to an existing building and/or has plumbing, regardless of its size, a building permit is required.
- Finishing a basement, if the work proposed includes any of the following,
 - structural or material alterations
 - installing or modifying heating and or plumbing systems
 - excavating and/or constructing foundations
 - basement underpinning
 - constructing a basement entrance
 - adding a second suite
- Energy and environmental building improvements, such as
 - rooftop stormwater retention systems
 - green roofs
 - structures used in the support of a wind turbine generator with a rated output of more than 3kW
 - solar projects such as installation of solar collector systems and solar hot water systems
- Construct a retaining wall more than one metre (3 feet 3 inches) in height provided the retaining wall is on or adjacent to public property (including streets), building entrances, and on private property accessible to the public.” [15]

Appendix G: Threat Analysis

Table 17 below is a list of possible threats to the archive collection we have found and what damage they may cause.

Table 17: Threat Analysis

Threat	Description
Improper lighting	The basement has fluorescent lights, which can be estimated to produce around 1600-3200 lumens (Appendix B). This surpasses the ideal range for illuminance specified in subsection 5.3 (54-107 lumens). This is dangerous because excess lighting can deteriorate paper media (Appendix B).
Improper temperature and humidity	The estimated average temperature and humidity deviates from the ideal range required to keep the archive space safe specified in subsection 5.3 (45% - 55% and 18°C - 22°C).
Water Stains	There are several water stains on the walls of the basement. This may be due to pipe leakage from internal drain pipes. Considering the building is historical, the internal pipes have aged a significant amount and are prone to leaks [30]. Additionally, the stains can increase the overall humidity of the basement [31].
Ceiling cracks and holes	There are holes near the corners of the ceiling of the basement. They are most likely due to internal drain pipe leakage deteriorating the ceiling foundation [32]. This is where the water leaked through in the adjacent room (Appendix B). These holes can collect heat from the air in the basement, which can decrease its overall temperature [32].

$$\begin{aligned}
 & (24.5 \times 28) + (198 \cdot 24.5) + (17 \cdot 216) + (26.5 \cdot 18) \\
 & + (28 \cdot 18) + (28 \cdot 216) + (36 \cdot 28) + (24 \cdot 131) \\
 & + (72 \cdot 28) + (12 \cdot 103) + (28 \cdot 18) + (28 \cdot 282) \\
 & + (36 \cdot 28) + (36 \cdot 12) \times 4 \\
 & = 32695.2 \text{ in}^2 \\
 & \text{Area} = 21.094 \text{ m}^2
 \end{aligned}$$

Figure 17. Area calculations

Appendix I: Morph Chart for Idea Generation

The team generated the ideas for the secondary functions identified by using the Morph Chart below (Table 18).

Table 18. Idea for secondary functions before feasibility check

	Temperature controlled	Humidity controlled	Light controlled	Air particulate controlled
Means	Fans	Humidifier	Switches	Electrostatics
	Portable heaters	Dehumidifier	Lamps	Roomba
	Portable coolers	Sand	Fire	Industrial filters
	Metal foil on walls	Plants	Motion sensors	Air purifier
	Ice	Pools	Piezoelectric crystals	Microfiber dusting cloth
	Cold rocks	Hot rocks	Nuclear fission	Swiffer
	Bucket of Water	Elevate content	Bulb type	Cotton rag
	Resistor heater	Plastic Sheet covering	Fireflies	Cleaners
	Greenhouse	Fire	UV filters	Broom
	Air conditioner	Exhaust Fan	Glowsticks	Sticky tape

	Ventilated boxes	Sawdust	Flashlight	???
	Refrigerators	Fix leaks	Neon lights	House plants
	Dry ice	Fountain	Candles	Radiation
	Liquid nitrogen	Fans	Repaint lights	Bucket of glue
	Fire	Moisture Absorber	Head lamps	Dust ??? net
	Thermoelectric coolers	Water pipes	Floor lights	Chinchilla (bathes in dust) :
	Cold water pipes	Duct tape whole room	Bioluminescence	Dust and wipe down surfaces
	Plants	Cleaners	Fan	Vacuum regularly
	People	Paper towels	Reflective strips	Use desiccant
	Inert liquid	Mist	Smaller bulbs	Mop floors
	Device that controls fans	Giant Sponge	LED strips	
	Mist	Keep door opened	Helmet lights	Negative ion generator
	Blow fan across blocks of ice	Charcoal briquettes	Glow in the dark hooks	
	Raise the ceilings	Baking Soda	Light box	Dusk-proof bookcase
	Seals to door	Insulate pipes	Holiday lights	
	Rug	Use desiccant	Plasma Lamp	
	Geothermal heat pump	Silica gel in containers	Solar lights	
	Thermal mass bookshelf	Microwave	Phone flash	
	Thermal mass table		Dimmer switches for lights	

	Tesla coil		Light box	
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Appendix J: Morph Chart Post-Feasibility Check

The team performed feasibility check checking primarily for constraints 1-6 (Table 19).

Table 19. Idea for functions after feasibility check

	Temperature controlled	Humidity controlled	Light controlled	Air particulate controlled
Means	Fans	Humidifier	Switches	Electrostatics
	Portable heaters	Dehumidifier	Lamps	Roomba
	Portable A/C unit	Sand	Fire	Industrial filters
	Metal foil on walls	Plants	Motion sensors	Air purifier
	Ice	Pools	Piezoelectric crystals	Microfiber dusting cloth
	Cold rocks	Hot rocks	Nuclear fission	Swiffer
	Water	Elevate content	Change Bulb type (other types of bulbs)	Cotton rag
	Resistive heater	Plastic Sheet covering	Fireflies	Cleaners
	Greenhouse	Fire	UV filters	Broom
	Air conditioner	Exhaust Fan	Glowsticks	Sticky tape
	Ventilated boxes	Sawdust	Flashlight	Robot
	Refrigerators	Fix leaks	Neon lights	House plants
	Dry ice	Fountain	Candles	Radiation
	Liquid nitrogen	Fans	Repaint lights	Bucket of glue
	Fire	Moisture Absorber	Headlamps	Dust repellent net
Thermoelectric	Water pipes	Floor lights	Chinchilla	

	coolers			
	Cold water pipes	Duct tape whole room	Bioluminescence	Dust and wipe down surfaces
	Plants	Cleaners	Fan	Vacuum regularly
	People	Paper towels	Reflective strips	Use desiccant
	Inert liquid	Mist	Smaller bulbs (size/illumination)	Mop floors
	Device that controls fans	Giant Sponge	LED strips	Negative ion generator
	Mist	Keep door opened	Helmet lights	Dust-proof bookcase
	Blow fan across blocks of ice	Charcoal briquettes	Glow in the dark tape	Aerial coagulants
	Raise the ceilings	Baking Soda	Night Vision goggles	Bag filter
	Seals to door	Insulate pipes	Holiday lights	Paper dryer sheets
	Rug	Use desiccant	Plasma Lamp	Ambient air gas control
	Geothermal heat pump	Silica gel in containers	Solar lights	Pipe air in and out through chimney
	Thermal mass bookshelf	Microwave	Phone flash	Circulate air within room
	Thermal mass table	Towel rug	Dimmer switches for lights	Bunny suit
	Reflective film	Mist the air	Light box	Hazmat suit
	Circulate air within room	Circulate air within room	Night Vision goggles	Tesla coil

	Pipe air in and out through chimney	Pipe air in and out through chimney		
	Microwave			
	Rockwool insulation			

Random Stimulation was used here to generate additional ideas:

Skateboard

-

Monkey

-

Banana

-

Red

Potato

Aluminum

- Sealed room
- Reflective film

Soap

- Aerial coagulants

Bag

- Bag filter

Coal

- Furnace

Photo

Paper

- Paper dryer sheets

Soda

- Ambient air gas control

Battery

Window

- Seal the room, only window to see inside

Towel

- Towel floor, soak up standing water

Snow

- Mist the air

Ocean

- Circulate air (ideally cold)

Mango

-

Straw

- Pipe air in and out

Shoes

- Bunny suit
- Hazmat suit

Muffin

-

Cactus

Appendix K: Solutions generated per member Post Feasibility Check

Each team member came up with 10-12 solutions that covered all the secondary functions by mixing and combining ideas from the morph chart. The first 7-8 for each member are directly from the morph chart and the last 3-4 were made using SCAMPER methods. Each of the tables below (Tables 20-25) list out each member's ideas.

Table 20. Sonnet's Solutions

Ideas	Temperature controlled	Humidity controlled	Light controlled	Air particulate controlled	Full Solutions
SS1	Metal Foils on walls	Charcoal Briquettes	UV filter	Air purifier	Metal foils will be attached to the walls to regulate temperature and charcoal briquettes will be placed in a pile to control humidity. UV filters will be attached to the lights to block UV radiation and an air purifier will be placed to filter impurities in the air.
SS2	Resistive Heater	Humidifier	Motion sensors	Aerial Coagulants	A resistive heater will be placed to regulate the temperature while a humidifier will be placed to regulate the humidity. Motion sensor lights will be attached to the ceiling to allow the archive space to have no lighting until a living thing walks in the room. Aerial coagulants will be placed to capture impurities in the air.
SS3	Ventilated boxes	Silica gel	Glow in the dark tape	Dust repellent nets	Archives will be kept in ventilated boxes to regulate their temperature and

					humidity. Silica gel will also be placed to control the humidity near the books. Glow in the dark tape will be attached to the walls to provide lighting and dust repellent nets will be attached to capture impurities in the air.
SS4	Seals to doors	Use desiccant	Night vision goggles	Industrial filters	The doors will be sealed to control temperature conditions and desiccant will be applied to all surfaces to control humidity. There will be no lighting but individuals can use Night vision goggles to access the room. Industrial filters will be placed to filter out impurities in the air.
SS5	Pipe air in and out through chimney	Elevate content	Change bulb type	Roomba	Air will be pumped in out of the room through the chimney in order to control the temperature. The archive content will be elevated to control the humidity it experiences. The bulb type will be changed to meet the objective illumination and a roomba will remove impurities.
SS6	Portable A/C unit	Plastic sheet covering	Floor lights	Microfiber dusting cloth	A portable AC unit will be placed to regulate the temperature while plastic sheet covering will be attached to all surfaces to regulate humidity. Floor lights will be attached to provide lighting and a microfiber dust cloth will be placed to capture impurities in the air.

SS7	Thermoelectric coolers	Exhaust fan	UV filters	Vacuum regularly	Thermoelectric coolers will be placed to regulate the temperature and an exhaust fan will be placed to regulate the humidity. UV filters will be attached to the lights to block UV radiation. A vacuum will be provided so that users can remove impurities.
SS8	Device that controls fans	Circulate air within room	UV filters	Air purifier	A device that controls fans will be placed along with fans themselves in order to control the temperature. Air will be circulated within the room to control the humidity. UV filters will be attached to the lights to block UV radiation and an air purifier will be placed to filter impurities in the air.
SS9	Ventilated boxes	Plants	Motion Sensors	Industrial filters	Archives will be kept in ventilated boxes to regulate their temperature and humidity. Additionally, plants will be placed to also regulate the humidity. Motion sensor lights will be attached to the ceiling to allow the archive space to have no lighting until a living thing walks in the room. Industrial filters will be placed to filter out impurities in the air.
SS10	Portable AC Units + Portable Heaters	Humidifier + Exhaust fan	UV filters + Motion Sensors	Air Purifier + Industrial Filter	Portable AC and heater units will be placed to regulate the temperature. A humidifier and an exhaust fan will be placed to regulate the humidity. Motion sensor

					lights will be attached to the ceiling to allow the archive space to have no lighting until a living thing walks in the room. UV filters will be attached to the lights to block UV radiation. An air purifier and an industrial filter will be placed to filter impurities in the air.
SS11	Device that controls fans + Pipe air in and out through chimney	Circulate air within room + Humidifier	Change bulb type + Motion Sensors	Air purifier + Dust Repellent nets	A device that controls fans will be placed along with fans themselves. In addition, the air in the room will be piped in and out through the chimney. This will regulate the temperature in the room. A humidifier will be placed and air will be circulated within the room to control humidity. Motion sensor lights will be attached to the ceiling to allow the archive space to have no lighting until a living thing walks in the room. Additionally, the light bulbs will be changed to meet the objective illumination. An air purifier with dust repellent nets will remove and filter out impurities in the air.
SS12	Ventilated boxes	Humidifier + Exhaust fan	UV filters + Motion sensors	Air purifier + Dust Repellent nets	Archives will be kept in ventilated boxes to regulate their temperature and humidity. A combination of a humidifier and an exhaust fan will be placed to also regulate humidity. Motion sensor lights will be attached to

					the ceiling to allow the archive space to have no lighting until a living thing walks in the room. UV filters will be attached to the lights to block UV radiation. An air purifier with dust repellent nets will remove and filter out impurities in the air.
SS13	Seals to doors + Thermoelectric coolers + resistive heaters	Circulate air within room + Humidifier	Change bulb type + Motion Sensors	Air Purifier + Industrial Filter	The doors will be sealed and a combination of thermoelectric coolers and resistive heaters will be placed to control temperature. A humidifier will be placed and air will be circulated within the room to control humidity. Motion sensor lights will be attached to the ceiling to allow the archive space to have no lighting until a living thing walks in the room. Additionally, the light bulbs will be changed to meet the objective illumination. An air purifier and an industrial filter will be placed to filter impurities in the air.

Table 21. Issa's Solutions

Ideas	Temperature controlled	Humidity controlled	Light controlled	Air particulate controlled	Full Solutions
IA1	Resistive heater	Use desiccant	Light box	Circulate air within room	The resistive heater controls the temperature of the room, while the desiccant controls humidity levels. Circulating air within the

					room regulates temperature and air quality, and a light box controls light.
IA2	Plants	Plants	Motion sensors	Air purifiers	Plants improve the temperature and humidity of the room. Air purifiers control air particulates. Motion sensors control lighting and maintain a well-lit environment.
IA3	Device that controls fans	Paper towels	Reflective strips	Negative ion generator	A device that controls fans regulates air flow and temperature, while negative ion generators can help remove harmful particles. Reflective strips can be used to improve visibility, and paper towels are used to improve humidity.
IA4	Ventilated boxes	Humidifier	Dimmer switches for lights	Industrial filters	Archives will be kept in ventilated boxes. Ventilated boxes improve air flow and maintain temperature, while humidifiers regulate humidity levels. Dimmer switches for lights control light levels and reduce energy consumption, and industrial filters remove harmful particles from the air.
IA5	Thermoelectric coolers	Exhaust fan	Floor lights	Dust repellent net	Thermoelectric coolers regulate temperature in the room, while exhaust fans remove stale air and moisture. Floor lights provide illumination, and dust repellent nets

					prevent dust and debris from accumulating.
IA6	Metal foils on walls	Saw dust	Solar lights	Microfiber dusting cloth	Metal foils on walls insulate the room to control temperature, while sawdust absorbs spills and prevents slip hazards. Solar lights provide illumination, and microfiber dusting cloths can be used to remove harmful particles
IA7	Seal doors	Silica gel in container	Smaller bulbs (size/illumination)	Mop floors	Sealing doors maintain temperature in the room, while silica gel in a container reduces humidity levels. Using smaller bulbs helps control light and mopping the floors can help remove dirt.
IA8	Pipe air in and out through chimney	Pipe air in and out through chimney	Floor lights	Roomba	Piping air in and out through a chimney can regulate temperature and humidity, while using floor lights provides illumination. Roombas remove dirt.
IA9	Rug	Charcoal briquettes	Glow in the dark tape	Dust-proof bookcase	Using a rug improves the temperature control, while charcoal briquettes absorb moisture. Glow in the dark tape improves light, and using a dust-proof bookcase protects books from dust and debris.
IA10	Thermal mass bookshelf	Silica gel in containers	Solar lights	Hazmat suit	Using a thermal mass bookshelf regulates

					temperature and humidity in the room, while silica gel in containers reduce moisture levels. Solar lights provide illumination, and a hazmat suit protects against harmful particulates.
IA11	Thermal mass table	Microwave	Helmet lights	Dust-proof bookshelves	Using a thermal mass table regulates temperature and humidity in the room, while a microwave to improve humidity. Helmet lights improve visibility, and using dust-proof bookshelves protects books from dust and debris.
IA12	Fire	Duct tape whole room	Reflective strips	Dust down and wipe surfaces	Fire regulates temperature in the room. Reflective strips improve visibility, and wiping surfaces can maintain cleanliness.

Table 22. Nafew's Solutions

Ideas	Temperature controlled	Humidity controlled	Light controlled	Air particulate controlled	Full Solutions
NI1	Fans	Humidifier	Lamp	Roomba	Fans will be placed to regulate the temperature in the room and a Humidifier will be placed to regulate the humidity. A Lamp will be placed to provide sufficient lighting to the books and a Roomba will roam the room to filter out impurities.
NI2	Portable	Sand	Motion Sensor	Air purifier	Portable coolers will be

	Coolers		lights		placed to regulate the temperature and sand will be placed to change the humidity of the room. Motion sensor lights will be attached to the ceiling. This will only cause lighting to be activated when there is motion. An air purifier will be placed to filter impurities in the air.
NI3	Metal Foil on walls	Pool	Piezoelectric crystal powered lights	Microfiber dusting cloth	Metal foils on the walls will be placed to change the temperature and a pool will be placed to change the humidity. Piezoelectric crystal powered lights will be attached to the floor to allow lights to only be activated when a living thing walks in. A microfiber cloth will be placed to capture impurities in the air.
NI4	Cold rocks	Elevate content	Change bulb type	Cotton Rag	Cold rocks will be placed to change the temperature and elevating archive content will change the humidity experienced by the archive. The bulb type will be changed to a light bulb that meets the objective illuminance and a cotton rag will be placed to capture impurities in the air.
NI5	Water	Plastic sheet covering	UV filters	Sticky tape	Filling parts of the room with water will change the temperature and adding plastic sheet covering to all surfaces will change the humidity. UV filters will be attached to the lights to block UV radiation from the lights and sticky tape will be

					placed to capture impurities in the air.
NI6	Resistor heater	Fire	UV filters	Broom	A resistor heater will be placed to regulate the temperature and fire will be lit in the fireplace to regulate the humidity. UV filters will be attached to the lights to block UV radiation from the lights and a broom will remove impurities in the air.
NI7	Rug	Insulate Visible Pipes	Holiday lights	Bag filter	A rug will be placed on the floor to change the temperature of the room while all visible pipes will be insulated to change the humidity. Holiday lights will be attached on the walls to provide lighting while a bag filter will be placed to filter out impurities in the air.
NI8	Blow fan across blocks of ice	Charcoal Briquettes	Glow in the dark tape	Negative ion generator	Blowing a fan across blocks of ice will change the temperature while charcoal Briquettes will be placed to change the humidity. Glow in the dark tape will be attached to the walls to provide lighting while a Negative ion generator will be placed to capture impurities in the air.
NI9	Thermoelectric coolers	Duct tape whole room	Floor lights with LED strips	Dust and wipe down surfaces with a robotic cleaner	Thermoelectric coolers will be placed to regulate the temperature while duct taping the whole room will change the humidity. Floor lights and LED strips will be attached to provide lighting and a robotic cleaner will remove impurities.

NI10	A mini garden featuring plants and cold rocks	Paper towels	Reflective strips	Vacuum regularly with a robotic cleaner	A mini garden with plants and cold rocks will be placed to change the temperature and paper towels will be placed to decrease the humidity. Reflective strips will be attached to the walls to provide lighting while a robotic cleaner that vacuums will remove impurities.
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Table 23. Matthew's Solutions

Ideas	Temperature controlled	Humidity controlled	Light controlled	Air particulate controlled	Full Solutions
ML1	Circulate air within room	Portable Humidifier/Dehumidifier Combo	Headlamps	Air purifier	Air will be circulated within the room to control the temperature. A portable humidifier and dehumidifier will be placed to control the humidity. Headlamps will be attached to the ceiling to provide lighting and an air purifier will be placed to filter impurities in the air.
ML2	Circulate air within room	Charcoal briquettes	Motion sensors	Swiffer	Air will be circulated within the room to control the temperature. Charcoal briquettes will be placed to control the humidity. Motion sensor lights will be attached to the ceiling and activated only when a living thing enters. A swiffer will be used to remove impurities.
ML3	Rockwool insulation	Portable Humidifier/Dehumidifier Combo	Night Vision goggles	Bunny suit	Rockwool insulation will be attached to the walls to control the temperature. A portable humidifier and dehumidifier will be placed to control the humidity. There will be

					no lighting but users can use night vision goggles. A bunny suit will be used to remove impurities.
ML4	Rockwool insulation	Charcoal briquettes	Headlamps	Negative ion generator	Rockwool insulation will be attached to the walls to control the temperature. Charcoal briquettes will be placed to control the humidity. Headlamps will be attached to the ceiling to provide lighting and a negative ion generator will be placed to capture impurities in the air.
ML5	Portable A/C unit+Resistive Heaters	Charcoal briquettes	Reflective strips	Air purifier	A Portable AC unit and resistive heater will be placed to regulate the temperature. Charcoal briquettes will be placed to control the humidity. Reflective strips will be attached to the walls to provide lighting and an air purifier will be placed to filter impurities in the air.
ML6	Portable A/C unit+Resistive Heaters	Portable Humidifier/Dehumidifier Combo	Motion sensors	Air purifier	A Portable AC unit and resistive heater will be placed to regulate the temperature. A portable humidifier and dehumidifier will be placed to control the humidity. Motion sensor lights will be attached to the ceiling and activated only when a living thing enters. An air purifier will be placed to filter impurities in the air.
ML7	Portable A/C unit+Resistive Heaters	Exhaust Fan	Headlamps	Industrial Filter	A Portable AC unit and resistive heater will be placed to regulate the temperature. An exhaust fan will be placed to

					regulate the humidity. Headlamps will be attached to the ceiling to provide lighting and an industrial filter will filter impurities in the air.
ML8	Portable A/C unit+Resistive Heaters	Plants (succulents)	Candles	Bunny suit	A Portable AC unit and resistive heater will be placed to regulate the temperature. Plants will be placed to control the humidity. Candles will be lit across the room to provide lighting. A bunny suit will be used to remove impurities.
ML 9	Portable HVAC out the chimney	Exhaust Fan	Lights	Enclosed room + Robots that collect boxes	A portable HVAC system that connects to the chimney will be installed to regulate the temperature. An exhaust fan will be placed to regulate the humidity. Lights will remain the same. The room will be further enclosed and robots that collect boxes will be deployed to remove impurities.
ML10	Portable HVAC out the chimney	Exhaust fan	Motion sensors	Enclosed room + bunny suits	A portable HVAC system that connects to the chimney will be installed to regulate the temperature. An exhaust fan will be placed to regulate the humidity. Motion sensor lights will be attached to the ceiling and activated only when a living thing enters. The room will be further enclosed and bunny suits will be used to remove impurities.

Table 24. Khadija's Solutions

Ideas	Temperature controlled	Humidity controlled	Light controlled	Air particulate controlled	Full Solutions
KM1	Ventilated Boxes	Exhaust Fans	UV Filters	Air purifier	Archives will be kept in ventilated boxes and exhaust fans will be used to maintain humidity levels. UV filters and air purifiers will also be installed.
KM2	Thermoelectric boxes	Humidifier	Floor lights	Roomba	Archives will be kept in thermoelectric boxes. Floor lights and a humidifier will be installed. Roomba will be used to electrically vacuum dust.
KM3	Thermal mass bookshelf	Use desiccant	Lamps	Dust repellent	Archives will be kept in thermal mass bookshelves and lamps will be placed at the corners of the room. Desiccants will be used to control moisture in the atmosphere and dust repellents will be used to reduce air particulates.
KM4	Thermoelectric coolers	Elevate content	Smaller bulbs/lighting	Negative ion generator	Thermoelectric coolers will be kept inside the room and the archives will be elevated. Smaller bulbs will be utilized for lighting and a negative ion generator to attract dust particles so we can extract and remove them.
KM5	Fans	Fix leaks	LED strips	Dust-proof bookcase	Fans will be installed and leaks will be fixed. LED strips will run along the room as lighting. All archives will be kept in a dust-proof case.
KM6	Portable	Insulate pipes	Dimmer	Air purifier	Portable coolers will be

	coolers		switches for lights		kept inside. Pipes will be insulated and dimmer switches for lights will be used to reduce light intensity. Air purifiers will also be used to reduce air particulate.
KM7	Liquid nitrogen	Sand	Reflective lights	Hazmat suit	Liquid nitrogen will be placed in the room to control temperature. Sans will also be placed in a big bucket to reduce humidity. Reflective lights will run along the room and hazmat suits will be worn by anyone entering archival space to reduce air particulates.
KM8	Pipe air in and out through chimney	Plastic Sheet covering	Glowsticks	Vacuum regularly	Pipe air in and out through the chimney to circulate the air and control temperature. Plastic Sheet covering to protect archives and glowsticks will be used for lighting. Space will be vacuumed regularly for dusting.
KM9	Dry ice	Plants	Glow in the dark tape	Pipe air in and out through chimney	Dry ice in a big bucket will be used to maintain temperature and plants will be kept to control moisture. Glow in the dark tape for lighting. Pipe air in and out through the chimney to circulate the air and reduce air particulates.
KM10	Fans	Sawdust	Helmet lights	Bag filter	Fans will be installed. Plants will be kept to control moisture. Helmet lights will be used and a bag filter to reduce dust.
KM11	Portable AC unit and	Charcoal briquettes	Lanterns	Handheld vacuum	A Portable AC unit and heaters will be placed in

	heaters	and elevate content			the room. Charcoal briquettes will be used and contents/archives will also be elevated. Lanterns and a handheld vacuum will also be utilized for light and dusting.
KM12	Portable power plus drum fan	Elevate content	Solar lights	Rubber Air blower	Portable power plus drum fan will be placed in the room. Archives will be elevated and solar lights will be used. A Rubber Air blower will be utilized for dusting.
KM13	Portable AC unit and heaters	Humidifier & Dehumidifier	Lanterns	Handheld vacuum	Portable AC unit, heaters Humidifier and Dehumidifier will be placed in the room. Lanterns and a handheld vacuum will also be utilized for light and dusting.

Table 25. William's Solutions

Ideas	Temperature controlled	Humidity controlled	Light controlled	Air particulate controlled	Full Solutions
WW1	Thermal mass bookshelves	Humidifier & Dehumidifier	Dimmer switches for lights	Dust-proof bookcase	The archive will be stored in thermal mass bookshelves to regulate its temperature. A portable humidifier and dehumidifier will be placed to regulate the humidity. A dimmer switch will be attached to control the lighting. The bookshelves will be encased in a dust proof bookcase.
WW2	Thermal mass Table	Exhaust Fan	UV filters	Vacuum regularly	A thermal mass table will be placed to regulate the temperature. An exhaust fan will be placed to regulate the humidity. UV

					filters will be attached to the lights to block UV radiation. A vacuum will be provided so that users can remove impurities themselves.
WW3	Portable heaters Dry Ice	Exhaust Fan	Helmet Lights	Dust-proof bookcase	Portable heaters and dry ice will be placed to control temperature. An exhaust fan will be placed to regulate the humidity. Helmet lights will be attached to the ceiling to provide lighting and the books will be encased in a dust proof bookcase.
WW4	Resistive Heater Liquid nitrogen	Fans	Phone flash	Robot cleaner	A Resistive heater will be placed during the winter and liquid nitrogen will circulate the room during the summer in order to control the temperature. Fans will be placed to control humidity. A phone flashlight will be attached to the ceiling to provide lighting and a robotics cleaner will remove impurities.
WW5	Portable Heater Portable A/C	Fix leaks	Floor lights	Air purifier	A Portable AC unit and heater will be placed to regulate the temperature. The leaks in the environment will be fixed in order to control the humidity. Lights will be attached to the floor to provide lighting and an air purifier will be placed to filter impurities in the air.
WW6	Ventilated boxes	Fix leaks	Motion sensors	Microfiber dusting cloth	Archives will be kept in ventilated boxes to control temperature and humidity within. The leaks in the environment

					will be fixed in order to control the humidity. Motion sensor lights will be attached to the ceiling and activated only when a living thing enters. A microfiber dusting cloth will capture impurities in the air.
WW7	Rockwool insulation	Pipe air in and out through chimney	Motion sensor	Vacuum regularly	Rockwool insulation will be attached to the walls to control the temperature. Air will be piped in and out through the chimney to regulate the humidity. Motion sensor lights will be attached to the ceiling and activated only when a living thing enters. A vacuum will be provided so that users can remove impurities themselves.
WW8	Device that controls fan	Desiccant	LED strips	Mop floors	A device that controls fans will be placed along with fans themselves in order to control the temperature. A desiccant will be applied to control the humidity. LED strips will be attached to the ceiling to provide lighting. A mop will be provided so that users can remove impurities themselves.
WW9	Rockwool insulation	Keep door opened	Smaller bulbs (size/illumination)	Dust and wipe down surfaces	Rockwool insulation will be attached to the walls to control the temperature. The door will remain open to keep the humidity at an acceptable level. The light bulbs will be smaller in illumination and size. Cleaners will be hired to dust and wipe down surfaces to remove impurities.

WW10	Plants	Plants	Candles	House plants	Plants will be placed to control temperature, humidity and remove impurities. Candles will be lit and placed across the room to provide lighting.
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Appendix L: Multi-voting

The team used multivoting as a method for reducing the number of solutions after idea consolidation and the generation of solutions through it. After multi-voting we settled on 10 ideas that were further evaluated on other criteria. We had two rounds of multivoting (Table 26 and 27). After the first round, there were 32 out of the original 69 solutions remaining. After another round we were able to determine our Top 10 ideas.

Ideas left post Multi-voting: SS10, ML6, SS11, SS12, IA8, WW9, SS13, WW5, ML9, KM13

Table 26. Multi-voting Round 1 (Every member had 10 votes)

Multivoting #1 (10 votes each)											
Sol. No.	Solution Description				SS	M L	NI	W W	K M	I A	Total
	Temperature controlled	Humidity controlled	Light controlled	Air particulate controlled	10	10	10	10	10	10	
SS10	Portable AC Units + Portable Heaters	Humidifier + Exhaust fan	UV filters + Motion Sensors	Air Purifier + Industrial Filter	1	1	1	1	1	1	6
NI9	Thermoelectric coolers	Duct tape whole room	Floor lights with LED strips	Dust and wipe down surfaces with a robotic cleaner	1		1	1	1	1	5
ML6	Portable A/C unit+Resistive Heaters	Portable Humidifier/De humidifier Combo	Motion sensors	Air purifier		1			1	1	3
IA8	Pipe air in and out through chimney	Pipe air in and out through chimney	Floor lights	Roomba		1		1		1	3
WW9	Rockwool insulation	Keep door opened	Smaller bulbs (size/illumination)	Dust and wipe down surfaces			1	1		1	3
ML3	Rockwool insulation	Portable Humidifier/De	Night Vision goggles	Bunny suit	1		1			1	3

		humidifier Combo										
ML7	Portable A/C unit+Resistive Heaters	Exhaust Fan	Headlamps	Industrial Filter			1	1	1			3
SS11	Device that controls fans + Pipe air in and out through chimney	Circulate air within room + Humidifier	Change bulb type + Motion Sensors	Air purifier + Dust Repellent nets	1				1			2
SS12	Ventilated boxes	Humidifier + Exhaust fan	UV filters + Motion sensors	Air purifier + Dust Repellent nets			1		1			2
SS13	Seals to doors + Thermoelectric coolers + resistive heaters	Circulate air within room + Humidifier	Change bulb type + Motion Sensors	Air Purifier + Industrial Filter	1						1	2
WW5	Portable Heater Portable A/C	Fix leaks	Floor lights	Air purifier				1	1			2
SS5	Pipe air in and out through chimney	Elevate content	Change bulb type	Roomba		1		1				2
KM1	Ventilated Boxes	Exhaust Fans	UV Filters	Air purifier	1		1					2
WW11	Resistive Heater Liquid nitrogen	Fans	Lanterns	Robot cleaner	1				1			2
WW6	Ventilated boxes	Fix leaks	Motion sensors	Microfiber dusting cloth	1			1				2
WW10	Plants	Plants	Candles	House plants	1	1						2
ML 9	Portable HVAC out the chimney	Exhaust Fan	Lights	Enclosed room + Robots that collect boxes						1		1
KM13	Portable AC unit and heaters	Humidifier & Dehumidifier	Lanterns	Handheld vacuum		1						1
WW7	Foam insulation	Pipe air in and out through chimney	Motion sensor	Vacuum regularly		1						1
SS7	Thermoelectric coolers	Exhaust fan	UV filters	Vacuum regularly			1					1
SS8	Device that controls fans	Circulate air within room	UV filters	Air purifier		1						1

IA3	Device that controls fans	Paper towels	Reflective strips	Negative ion generator						1	1
IA10	Thermal mass bookshelf	Silica gel in containers	Solar lights	Hazmat suit						1	1
NI3	Metal Foil on walls	Pool	Piezoelectric crystal powered lights	Microfiber dusting cloth						1	1
NI4	temperature stable rocks	Elevate content	Change bulb type	Cotton Rag		1					1
NI8	Blow fan across blocks of ice	Charcoal Briquettes	Glow in the dark tape	Negative ion generator	1						1
ML5	Portable A/C unit+Resistive Heaters	Charcoal briquettes	Reflective strips	Air purifier			1				1
ML10	Portable HVAC out the chimney	Exhaust fan	Motion sensors	Enclosed room + bunny suits		1					1
KM3	Thermal mass bookshelf	Use desiccant	Lamps	Dust repellent				1			1
KM11	Portable AC unit and heaters	Charcoal briquettes and elevate content	Lanterns	Handheld vacuum			1				1
KM12	Portable power plus drum fan	Elevate content	Solar lights	Rubber Air blower					1		1
WW1	Thermal mass bookshelves	Humidifier & Dehumidifier	Dimmer switches for lights	Dust-proof bookcase				1			1
SS1	Metal Foils on walls	Charcoal Briquettes	UV filter	Air purifier							0
SS2	Resistive Heater	Humidifier	Motion sensors	Aerial Coagulants							0
SS3	Ventilated boxes	Silica gel	Glow in the dark tape	Dust repellent nets							0
SS4	Seals to doors	Use desiccant	Night vision goggles	Industrial filters							0
SS6	Portable A/C unit	Plastic sheet covering	Floor lights	Microfiber dusting cloth							0
SS9	Ventilated boxes	Plants	Motion Sensors	Industrial filters							0
IA1	Resistive heater	Use desiccant	Light box	Circulate air within room							0
IA2	Plants	Plants	Motion sensors	Air purifiers							0

KM5	Fans	Fix leaks	LED strips	Dust-proof bookcase																0
KM6	Portable coolers	Insulate pipes	Dimmer switches for lights	Air purifier																0
KM7	Liquid nitrogen	Sand	Reflective lights	Hazmat suit																0
KM8	Pipe air in and out through chimney	Plastic Sheet covering	Glowsticks	Vacuum regularly																0
KM9	Dry ice	Plants	Glow in the dark tape	Pipe air in and out through chimney																0
KM10	Fans	Sawdust	Helmet lights	Bag filter																0
WW2	Thermal mass Table	Exhaust Fan	UV filters	Vacuum regularly																0
WW3	Portable heaters Dry Ice	Exhaust Fan	Helmet Lights	Dust-proof bookcase																0
WW4	Resistive Heater Liquid nitrogen	Fans	Phone flash	Robot cleaner																0
WW8	Device that controls fan	Desiccant	LED strips	Mop floors																0

Table 27. Multivoting Round 2 (Every Member has 4 votes)

Sol.No.	Solution Description				S	M	N	W	K	I	Total
					S	L	I	W	M	A	
	Temperature controlled	Humidity controlled	Light controlled	Air particulate controlled	4	4	4	4	4	4	
SS10	Portable AC Units + Portable Heaters	Humidifier + Exhaust fan	UV filters + Motion Sensors	Air Purifier + Industrial Filter	1	1	1	1		1	5
ML6	Portable A/C unit+Resistive Heaters	Portable Humidifier/De humidifier Combo	Motion sensors	Air purifier			1	1	1	1	4
SS11	Device that controls fans + Pipe air in and out through chimney	Circulate air within room + Humidifier	Change bulb type + Motion Sensors	Air purifier + Dust Repellent nets	1		1		1	1	4

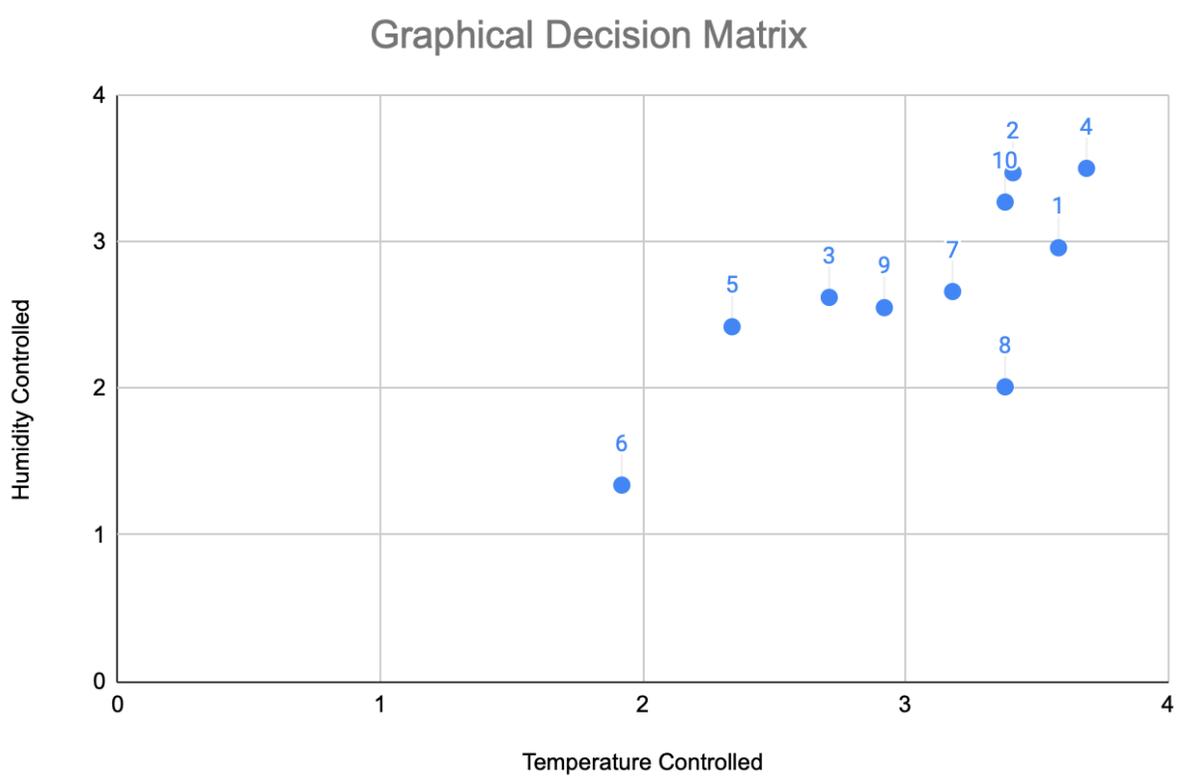


Figure 18. Graphical Decision Matrix with main objectives on the axis

Appendix N: Design Quality Objective Estimations

To assess the quality of our three alternative designs, we estimated the objective metric each design could achieve, and compared to our objective goals.

Table 29. Objective, Metric and Goal

Objective	Metric	Goal
Temperature controlled	Absolute value of (temperature in °C - 20)	Less than or equal to 2

Design 1: Environmentally Controlled Archive Cabinet
 Looking at a reference commercial off the shelf product, we know a environmentally controlled cabinet can achieve our objective of 20 °C, thus the absolute value difference is 0 °C [33]

Design 2: Insulated Basement

100mm rockwool insulation has an R-value of 2.7 m²K/W. Thus combining it with mud brick, the total R-value for this design will be 2.7+0.27 = 2.97 m²K/W.

Heating: Power required to heat (W) = $(196 \text{ m}^2)(36 \text{ }^\circ\text{C})/(2.97 \text{ m}^2\text{K/W}) = 2376 \text{ W}$
 Cooling: Power required to cool (W) = $(196 \text{ m}^2)(7 \text{ }^\circ\text{C})/(2.97 \text{ m}^2\text{K/W}) = 462 \text{ W}$

Electric Baseboard Heater: 2500 W [34] (meets heating requirement)

Portable AC: approximately 1,466 W [35] (assuming it runs at 5000 BTU for one hour, this meets the cooling requirement)

Since both the heating and cooling requirements are met, we can achieve our objective of 20°C, thus the absolute value difference is 0°C.

Design 3: Basic Portable HVAC

Using temperature data from Appendix B, we know the maximum temperature differential during the winter (heating) to be $20 - (-16) = 36 \text{ }^\circ\text{C}$.

During the summer (cooling), the temperature differential will be $27 - 20 = 7 \text{ }^\circ\text{C}$.

Using measurements from Appendix B, we can estimate the surface area of the room to be $30*2 + 5.94*6.2*2 + 5.03*6.2*2 = 196 \text{ m}^2$

Mud brick has an r-value of $0.27 \text{ m}^2\text{K/W}$ [36]

Using the energy loss equation, we can calculate the amount of energy required to heat and cool the room.

Heating: Power required to heat (W) = $(196 \text{ m}^2)(36 \text{ }^\circ\text{C})/(0.27 \text{ m}^2\text{K/W}) = 26133 \text{ W}$

Cooling: Power required to cool (W) = $(196 \text{ m}^2)(7 \text{ }^\circ\text{C})/(0.27 \text{ m}^2\text{K/W}) = 5081 \text{ W}$

6 Portable Heaters: $6*4800 \text{ W} = 28800 \text{ W}$ [37] (meets heating requirement)

Portable AC: $4,692 \text{ W} * 2 = 9384 \text{ W}$ [38] (meets cooling requirement)

Since both the heating and cooling requirements are met, we can achieve our objective of 20°C, thus the absolute value difference is 0°C.

Table 30. Second Objective, Metric and Goal

Objective	Metric	Goal
Humidity controlled	Absolute value of (relative humidity in % - 50)	Less than or equal to 5 [8]

Design 1: Environmentally Controlled Archive Cabinet

Looking at a reference commercial off the shelf product, we know a environmentally controlled cabinet can achieve our objective of 50% humidity, thus the absolute value difference is 0% [31]

Design 2: Insulated Basement

The calculations are identical to design 3 below as 1 COTS humidifier, and 1 COTS dehumidifier will be sufficient to meet our objective of 50% humidity, thus the resultant absolute value difference is 0%.

Design 3: Basic Portable HVAC

Using values from Appendix B, the volume of the box is roughly $(30 \text{ m}^2)(6.2\text{m}) = 186 \text{ m}^3$. 100% humidity air holds 17 g/m^3 of water at 20°C [39]. This means that at most, there will be $(17\text{g/m}^3)(186 \text{ m}^3) = 3162 \text{ g}$ of water

Using a commercial off the shelf product, we know a dehumidifier can remove 50 pints/day from the air, or 23658 g/day [40]. Thus, one dehumidifier will well exceed the requirements to decrease the humidity to 50%.

For increasing humidity, we are no longer relying on the natural gas furnace to heat the room, and thus there will be less loss of humidity. Additionally, we have found a commercial off the shelf product that is rated for 1000 ft^2 , or 93 m^2 [41]. Our room is 30 m^2 thus one humidifier will well exceed the requirements to increase the humidity to 50%.

Thus, the resultant absolute value difference from our objective is 0%.

Table 31. Third Objective, Metric and Goal

Objective	Metric	Goal
Air particulate controlled	Level of Filtration (%)	≥ 60

Design 1: Environmentally Controlled Archive Cabinet

In this design, each cabinet will be installed with a HEPA filter, filtering out 99.97% of particles [42].

Design 2: Insulated Basement

This design takes advantage of a COTS standalone air purifier, with a rated area coverage of 60 m^2 filtering 99.97% of particles by utilizing a HEPA filter [43].

Design 3: Basic Portable HVAC

In this design we will install a user operated vacuum containing a HEPA filter which filters 99.97% of particles [44].

Table 32. Fourth Objective, Metric and Goal

Objective	Metric	Goal
Light controlled	Average Lux (lx)	$\leq 100\text{lux}$ [9]

For our lux measurement, we are estimating the average lux hours the books are exposed to per hour. All designs allow for 0 lux exposure when the user is not around.

The librarian needs to access the room for 3 days a week, at 5 hours/day, meaning the contents will be exposed to a maximum of 15 hours of light per week. One week has a total of $24 \times 7 = 168$ hours. All designs also allow for localized lighting, meaning only the area around the user will be lit. However, if the user spends all their time in one place, we know there will be a maximum of 15 hours of light exposure per week in all designs.

Design 1: Environmentally Controlled Archive Cabinet

In this design, we can assume that each cabinet is lit to provide 150 lux as recommend for archives [45]. Because each cabinet is only lit when the cabinet door is opened, we know that the maximum average lux the books will be exposed to is $(150 \text{ lux})(15 \text{ hours})/(168 \text{ hours}) = 13.4 \text{ lux}$.

Design 2: Insulated Basement

The current lights emit roughly 200 lux onto the archives thus the books will be exposed to a maximum average of $(200 \text{ lux})(15 \text{ hours})/(168 \text{ hours}) = 17.9 \text{ lux}$ [46].

Design 3: Basic Portable HVAC

A typical camping lantern (with 150-300 lumens) provides roughly 100 lux at a distance of 1 meter [47]. For this design, the average maximum lux will be $(100 \text{ lux})(15 \text{ hours})/(168 \text{ hours}) = 8.9 \text{ lux}$.

Table 33. Fifth Objective, Metric and Goal

Objective	Metric	Goal
Quick to implement	Week(s) to implement	≤ 1

Design 1: Environmentally Controlled Archive Cabinet

Due to our design requiring customization of industrial scientific cabinets we can estimate our custom cabinets to have a 15 week lead time [48]. We can add on an estimated 1 week installation time to the large size of the custom cabinets. This gives us an estimated total time to implement of 16 weeks.

Design 2: Insulated Basement

This design also utilizes primarily COTS products which looking at Design 3 below will take 1 week to implement. However, the aspects of the design may take longer which are insulation install, new shelf assembly, and electrical plug install.

To install the rockwool insulation, the existing shelves will have to be removed. We can allocate 1 week to this.

For new shelves, assembly will also likely take around 1 week.

For electrical plug install, it will take 4 days to get an electrician to come out and install the plugs.

This brings the total time to implement to about 3.6 weeks.

Design 3: Basic Portable HVAC

Due to this design utilizing only COTS user installable products, the two factors affecting implementation time are shipping times, and a short period to set up the products. Shipping for in-stock products will be a maximum of 5 days [49]. Reserving 2 days for setup time, we get a total of 7 days (or 1 week) of implementation time.

Table 34. Sixth Objective, Metric and Goal

Objective	Metric	Goal
Maximize storage space	Storage space area (m ²)	≥ 21.094

Design 1: Environmentally Controlled Archive Cabinet

In this design (see section 6.3.2) we have 40 cabinets with 0.5304 m² storage area per cabinet giving us a total storage space of 21.2 m² [33].

Design 2: Insulated Basement

In this design, we utilize deeper shelves, but less aisles. We can thus achieve a similar storage area while maintaining aisle width in a smaller total area allowing the addition of a desk. In our configuration (see section 6.3.2), we get an estimated $4+4+4+1.5+1.5+4+1+1 = 22$ m² of total storage area.

Design 3: Basic Portable HVAC

In this design we reuse the existing shelves, thus our total storage area remains unchanged (21.094 m²)

Table 36. Seventh Objective, Metric and Goal

Objective	Metric	Goal
Maneuverable	Width of aisle (cm)	≥ 106.7

Design 1: Environmentally Controlled Archive Cabinet

In this design, our selected cabinets are 0.813 m deep [33], thus with five cabinet lines, we get $7.5 - 0.813 * 5 = 3.44$ for four aisles. $3.44 / 4 = 0.86$ m or 86 cm per aisle. The insulation from the cabinets decreases the design's maneuverability slightly.

Design 2: Insulated Basement

For this design, using deeper 0.76 m shelves, we can find with with four aisles, we get $(7.5 - 0.76 * 5) / 4 = 0.925$ m or 93 cm of aisle width, getting quite close to our 106.7 cm objective goal.

Design 3: Basic Portable HVAC

For this design, existing shelves were used, however in order to fit other equipment, aisle width had to be decreased in order to maintain storage area. In addition to this, running extension cords around the room also decreases the effective aisle width. Thus the estimated aisle width for this design is 32 inches (Appendix H) - $2 \text{ in} * 0.9 = 27 \text{ in} = 68.6 \text{ cm}$

Table 37. Eighth Objective, Metric and Goal

Objective	Metric	Goal
Usable for reading and processing	Square Metre (m ²)	1.52 m by 0.68 m desk space (Appendix B) Goal: 1.12 m ² of working area

All three designs implement the desk requested by the client (Appendix B) thus all have 1.12 m² of working area / desk space.

Table 38. Ninth Objective, Metric and Goal

Objective	Metric	Goal
Accessible	Required arms reach (cm)	≤ 84

Design 1: Environmentally Controlled Archive Cabinet

The depth of the cabinets is 68.6 cm and the height is 152.4 cm [36]. Thus, since the height is low, the maximum reach required for this design is 68.6 cm.

Design 2: Insulated Basement

This design uses 0.76m cabinets, thus the maximum reach is $0.76/2 = 0.38$ m or 38 cm since the shelves are accessible on both sides.

Design 3: Basic Portable HVAC

This design uses existing 0.6m cabinets, thus the maximum reach is $0.6/2 = 0.3$ m or 30 cm since the shelves are accessible on both sides.

Table 39. Tenth Objective, Metric and Goal

Objective	Metric	Goal
Electrically convenient	Number of available plugs	≥ 8

Design 1: Environmentally Controlled Archive Cabinet

In this design, we install a multitude of electrical plugs on the ceiling and walls. To power the environmentally controlled cabinets, electrical plugs are installed from the ceiling to avoid blocking aisles (one plug for each cabinet). On the walls we have a total of 4 outlet plates, giving us a total of 8 plugs on the walls. This gives us a total of 8 available plugs.

Design 2: Insulated Basement

This design includes wall plugs installed along the outer walls both to achieve 8 free electrical plugs as well as additional plugs to power the various portable HVAC units in the room.

Design 3: Basic Portable HVAC

This design runs extension cords through the doorway to the archive and splits these extension cords using surge protectors allowing for the inclusion of 8 free electrical plugs, as well as an additional 10 plugs for portable HVAC units.

Tables 40, 41, and 42 below explain how some specific components of each design achieve certain aspects of our environmental control objectives.

Table 40. How each component of Design 1 (Environmentally Controlled Archive Cabinet) contributes to the objective.

Objective	Which component of the design addresses the objective	How it addresses the objective
Temperature controlled	Insulated boxes	The insulated boxes help control the temperature of the books by isolating it in a ventilated container that keeps it at a relatively constant temperature.
Humidity controlled	Insulated boxes	Insulated boxes help reduce humidity by decreasing the amount of moisture that enters and prevent condensation on the boxes [50]
Light controlled	Motion sensors	Motion sensors used to ensure the object is only illuminated when clients need to access the archival space. Thus, light exposure is minimized (close to 50 lux) as the archival space is kept in darkness most of the time. [9] And UV filters will reduce lux slightly. [51]
Air particulate controlled	Air purifier and dust repellent nets	The HEPA air purifier can filter 99.97% of impurified air [52]. The dust repellent nets further removes any dust that remains and have been proven to decrease dust with 60% to 90% efficiency [53].

Table 41. How each component of Design 2 (Insulated Basement) contributes to the objective.

Objective	Which component of the	How it addresses the
-----------	------------------------	----------------------

	design addresses the objective	objective
Temperature controlled	Panel insulation, Portable AC, Electric baseboard heater	The rockwool insulation reduces the heating and cooling requirement (done by the portable AC and the heater) by minimizing the influence of outdoor temperatures.
Humidity controlled	Dehumidifier	The dehumidifier will remove 30 to 40 pints of humidity on average per day [54]
Light controlled	Motion sensors	Motion sensors used to ensure the object is only illuminated when clients need to access the archival space. Thus, light exposure is minimized (close to 50 lux) as the archival space is kept in darkness most of the time. [9] When the lighting system is activated, the tube lights will provide about 300 lux with respect to the entire room [46].
Air particulate controlled	Air purifier	The HEPA air purifier will suck in and filter 99.97% [52] of impurified air within the device and then release purified air.

Table 42. How each component of Design 3 (Basic Portable HVAC) contributes to the objective.

Objective	Which component of the design addresses the objective	How it addresses the objective
Temperature controlled	Portable AC and Portable heater	The portable AC can cool the room to the desired temperature and the portable heater can heat the room near the desired temperature.
Humidity controlled	Dehumidifier	The dehumidifier will remove

		30 to 40 pints of humidity on average per day and a humidifier increases the humidity by 30% to 40% a day [54]
Light controlled	Lantern	Light exposure is minimized (close to 0 lux) as the archival space is kept in darkness all the time [9]. And a typical camping lantern (with 150-300 lumens[47])can provide a lux level of approximately 50-100 lux at a distance of 1 meter
Air particulate controlled	Handheld vacuum	A handheld vacuum with a HEPA filter may be able to capture 99.97% of particles as small as 0.3 microns.[44]

Attribution Table:

If any required components are missing, your assignment is considered incomplete. It will accrue standard late penalties until completed.

Tutorial #: 0123

Team #: 144

Assignment: Conceptual Design SpecificationsDate: Mar 26, 2023

Section	Student Names					
	Matthew	Sonnet	Khadija	Issa	William	Nafew
Executive Summary	ET	WD, ET		ET		
1 Introduction		WD, FP				
2 Problem Statement	ET	WD, ET		ET	ET	ET
3 Service environment	ET OR1	OR2, OR3		ET	ET	RS, WD, OR3
4 Stakeholders		MR, ET		ET, RS	RS2 WD ET	
5 Detailed Requirements	WD			ET	ET	
5.1 Functions	WD, RS4				ET	
5.2 Objectives	ET	ET,	WD, RS6, ET, FP	RS6	ET	ET
5.3 Constraints				WD, RS3	ET	
6.1 Idea Generation	ET	WD, FP				
6.2 Alternative Design Selection	ET	WD, FP				
6.3.1 Environmentally	WD, ET, OR6	OR4, FP	ET	WD, RS4, RS5, RS6	RS4, RS6	ET

Controlled Archive Cabinet (Design 1)						
6.3.2 Insulated Basement (Design 2)	MR ET, OR6	OR4, FP	ET	RS4, RS5, RS6, ET	RS4, RS6	WD, RS4, RS5
6.3.3 Basic Portable HVAC (Design 3)	MR ET, OR6	OR4, FP	ET	RS4, RS5, RS6, ET	WD, RS4, RS6, ET	ET
7.0 Proposed Conceptual Design	ET	FP	WD, ET, FP	ET		
8.0 Measures of Success	WD ET	FP		ET		
9.0 Conclusion		WD, FP				
References					WD, ET	WD, ET
Appendix A	WD					
Appendix B	WD	WD	WD, ET			WD, ET
Appendix C		MR, ET			WD, ET	
Appendix D	WD					
Appendix E	WD	MR, ET	WD, RS5, ET			
Appendix F				WD, RS3		
Appendix G				ET	ET	WD, RS
Appendix H		WD, ET, OR3				
Appendix I	WD	WD	WD, OR5	WD, OR5	OR5	WD
Appendix J	WD	WD	WD, OR5	WD, OR5	OR5	WD
Appendix K	WD	WD	WD, OR5	WD, OR5	WD, OR5	WD
Appendix L	WD, ET	WD	WD, OR5	WD, OR5	ET, OR5	WD
Appendix M	WD, ET	WD		ET		WD

Appendix N	WD, ET, MR			WD, MR	WD, ET	WD, MR
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Fill in abbreviations for roles for each of the required content elements using the abbreviations found on the next page. You do not have to fill in every cell.

RS – Research (give details below)

WD – Wrote Draft

MR – Major Revision

ET – Edited

FP – Final Proofread of COMPLETE

DOCUMENT verifying for flow and consistency

OR – Other (give details below)

If you put RS (research) please add a number identifier such as RS1, RS2, etc. Give the research question / topic:

RS1: Estimation

RS2: Stakeholders related to library renovation

RS3: Constraint Generation Methods

RS4: Function Generation Methods

RS5: Objective Generation Methods

RS6: Researching objective metric goals

If you put OR (other) please add a number identifier such as OR1, OR2, etc. Explain the role below:

OR1: Estimations for temperature and humidity ranges

OR2: Pictures for service environment

OR3: Layout of shelves drawn through second site visit for service environment

OR4: Drawings of alternative designs

OR5: Idea generation process

OR6: Estimations for objective tables in appendix N

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