Applying Industrial Engineering Principles to Student Workspaces at Worcester Polytechnic Institute

A Major Qualifying Project

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Abstract

Our Major Qualifying Project was to assess and improve the efficiency of student workspaces at Worcester Polytechnic Institute (WPI) by applying industrial engineering techniques to three different campus buildings: Gordon Library, Higgins Laboratories, and the Innovation Studio. We had set our focus primarily on Gordon Library. Each of these workspaces possesses a unique set of needs and functions. The rationale of our team completing this project was to ensure that the design of student workspaces was fulfilled by considering consumer, space optimization, and resource utilization needs. Furthermore, our team recognized that a common problem faced in industrial operations is that stakeholders are not always aware of industrial engineering principles. Therefore, the design of such spaces are sometimes inefficient, underutilized, or wasteful. For these reasons, our team completed this project to analyze the current operation of the three aforementioned workspaces to highlight potential utilization and optimization flaws, while making recommendations to ensure the development of a more efficient workspace as alterations are made in the future. To produce these recommendations, our team used several different methods including: axiomatic design and analysis, survey distribution and analysis, and space optimization techniques. Due to the unique nature of each building, the results that the methods produced differed for each building. The results for Gordon Library indicated that the area for improvement was in space optimization. Thus, our team used survey data and space optimization methodologies to recommend improvements to the floor plan. These floor plans prioritized the resources that had the highest student usage during a term. We also recommended that the library consider the usage of visual capacity and availability displays to inform library users of the current availability status. The results for Higgins Laboratories indicated a need for an inventory management system. To fulfill this need, our team recommended an inventory and parts ordering system that uses both an Excel spreadsheet and a google form. Finally, for the Innovation Studio, the results displayed a need for improved methods to track space and resource utilization. Thus, we recommended the implementation of an occupancy tracker. We also recommended techniques such as collecting student feedback on the resources used during a term as well as a training decision tree to help with issues they were experiencing. Overall, our research confirmed phenomena of Industrial Engineering principles such as the Red Bead Experiment in which a system operates only as well as the process allows, and the importance of approaching problems using Axiomatic Design methodologies.

Chapter 1: Introduction

1.1 Problem Statement and Rationale

On Worcester Polytechnic Institute's(WPI's) campus, current stakeholders may not be aware of the inefficiencies affecting the workspaces they are provided. Which limits the academic value of on-campus resources for students and faculty alike. These inefficiencies in space utilization and workshop operational time hinders student learning potential which decreases the quality and price value of the education provided by WPI. Our project focuses on optimizing student interaction of an incoming experimentation lab in Higgins Laboratories, the Innovation Studios, and Gordon Library including individual study areas, lab operations, tech suites, inventory system, and other location-specific aspects.

From our preliminary observations and the team's previous use of the Higgins basement laboratories; including MQP lab space, robotics shops, and the Society of Automotive Engineer (SAE) shops, before our interviews with faculty and students using the space, the customers of the space seem to be students mainly in the Mechanical Engineering(ME), SAE, and Robotics departments. The available workshop space is primarily used for project development and hands-on machining opportunities for students. This space is currently not being used for any classes throughout the day. The operational status of the space includes old MQP Labs, which are being emptied of their equipment resulting in inefficient use of said space in addition to pushing old/unused resources into the hallway. In addition, many potential available workspaces are only being used as storage places for old projects and equipment. This limits the opportunity for students to utilize the space, combined with the fact that many students do not even know that these campus resources exist or they do not have the required training to operate the resources.

The Innovation Studios do not currently have any operational changes being made to the spaces available to students this includes the prototyping labs, studio labs, 3D-Printers, makerspace, and the active learning classroom. All of these resources are available to all current students, though the space is mainly used by robotics students. From a preliminary observation of the space, we have seen many issues with access to the resources available and students are experiencing excessive wait times for using equipment, specifically the 3D printers. Many of the bottlenecks involved in the 3D printing lab stem from an inefficient process and general machine malfunctions. Many of these resources need to be used for class projects. However, students are not able to get their projects completed in time due to the inefficiencies of the systems that are currently in place.

Gordon Library is currently underway in a five-year plan to remodel its entire floor space. This includes getting rid of many of its books and bookshelves to open up space to add more seating and workspaces. They have a current model for the basement and the third floor that they would like to improve on before designing the space, while also wanting to develop a model for the ground floor space. The library is aiming to better fit the needs of the students as that is shifting from the need for physical resources such as books to the need for more study space, access to computers, and space to work with groups on projects. Also, their goal is to have as much input from students using the space as possible through surveys throughout this academic school year as remodeling has already begun and will continue over the next couple of years.

1.2 Project Goals and Objectives

Our goal for this project was to organize campus workspaces, improve the available space, create a better and more efficient space for current students, and provide opportunities for new students to use the resources. Using the following methods to achieve space optimization best suited for the student experience;

- Student input Surveys
- Industrial Engineering Principles:
  - Axiomatic Design
  - Visual facility models
  - Engineering Economics
  - Management and Organizational tools

While these processes will look and function differently in each facility as the customers and usage of each space differ, overall they will achieve the same goal of increasing efficiency and opening up the resources to more customers, and limiting the difficulties found when using the spaces.

1.3 Project Scope

The research conducted in this Major Qualifying Project (MQP) was non-sponsored and campus-based. We focused on three campus locations to evaluate. As previously mentioned, these locations are the Gordon Library, Higgins Laboratories, and Innovation Studio. Each of the facilities has primary stakeholders, which are the students and faculty. Other secondary stakeholders are current and prospect vendors, donors, and upper management committees responsible for the spatial mapping and development of campus buildings.

Where the project group has decided to focus our research was decided based upon customer needs and prioritizing the most used aspects of the space. For instance, the entire library was under review for research in space optimization, whereas only the lowest floor in Higgins Laboratories was researched for efficiency. This decision was made based on a combination of conclusions of our axiomatic design, interviews with staff, and informal conversations with students that use these spaces.

1.4 Project Deliverables

- Library
  - Analyze models of floor plans (3rd floor and basement)
  - Student survey feedback
  - Axiomatic Design
  - Space Optimization Recommendations
  - Rational for floor plan suggestions
- Higgins
  - Axiomatic Design
  - Space Optimization Recommendations
  - Rational for floor plan suggestions
  - Potential Inventory System Design
  - Space Occupancy Recommendations
- Innovation
  - Axiomatic Design
  - Building Occupancy Recommendations
  - Potential Safety Training Decision Tree
  - Potential Student Feedback Designs

Chapter 2: Background

For our MQP, our team decided to narrow our focus to three unique collaborative spaces on campus. These spaces include Gordon Library, Higgins Laboratories, and the Innovation Studio. A description of each collaborative space within this study will be discussed in this section. To further analyze the unique elements, needs, and requirements of each facility we decided to use axiomatic design methods. The definition, context, and purpose of axiomatic design will be explored in this section. Lastly, we also implemented space optimization techniques to aid with our assessments. The definition, context, and purpose of the techniques used will be discussed in this section as well.

2.1 Overview of Three Case Study Collaborative Spaces

When selecting campus spaces as case studies in our research, our team wanted to select collaborative spaces with diverse assets. This section will explore a description of the purpose and dimensions of each collaborative space in our case study.

2.1.1 Operational Status of Gordon Library

Gordon Library is a four-floor building, parallel to Boynton St, on WPI's campus. Although this building has changed since its origin, its primary function remains the same: an additional space for students to access resources to aid their education. Moreover, Gordon Library houses the IT Service Desk, technologies (computers, scanners, printers), books, and journals available digitally and in print, tech suites, conference rooms, seating, and archives. These resources are spread throughout the four floors of the building. Additionally, each floor of the library has a unique theme in purpose. The second floor of the library, or the primary entrance, contains the library service desk as well as the IT service desk. This floor is designed to be more collaborative and there are mainly collaborative seating options available (tech suites, rectangular tables, and dogbone tables). As expected, this floor is usually the loudest since it has the primary entrance and is primarily designed for collaboration. By contrast, the first floor, also called the "quiet floor", right below, is designed for individual work. This floor houses bookshelves, a reflection space, and has individual seating. The basement, right beneath the first floor, is more similar to the second floor of the library. Classes are temporarily being held in a section of this floor, due to renovations on Kaven Hall, and the remainder of the floor is occupied by archives on bookshelves and collaborative seating. Lastly, the third floor is a combination of the lower floors. On this floor, a row of individual seats aligns one side of the floor, the remainder of the seating is collaborative, as well as housing bookshelves and computer spaces.

At present, the library collects data on its occupancy and capacity. This is done using door sensors that count and track the number of people entering and exiting the building, and by using software to monitor the usage of the tech suites. Gordon Library also frequently publishes surveys seeking student feedback on improving the resources within the library.

2.1.1.1 Past Research in Space Optimization of Gordon Library

The focus on applying Industrial Engineering principles to Gordon Library is a continuation of a project titled, “Recommendation Report for Optimizing Individual Study and Collaborative Spaces on Gordon Library’s Third Floor”. This project, advised by Kevin Lewis, was started and finished during the fall semester of 2019 by Kaelyn Hicks (‘22) and Paul Pacheco (‘22). The purpose of this project was to compose a recommendation report supported by statistical data to improve the optimization on the third floor of Gordon Library [19]. Through surveys and data analysis, this project highlighted an overall student need for more individual and collaborative seating [19]. Additionally, this project focused on finding ways to accommodate the needs for both quiet and collaborative spaces with additional resources, such as sound masking and dividers [19]. Kaelyn primarily focused on the derivation of the surveys, analysis of data, and development of 3D renderings for recommended floor plan layouts [19]. Paul focused on incorporating human factors and psychological applications, such as optimal lighting and seat position, to the selection of potential furniture options [19]. The end deliverables for this project were a detailed recommendation report that included a catalog of recommended furniture, access to survey data, and 3D renderings, and a rationale for the floor plan suggestions.

After assessing the team’s recommendation report, Gordon Library Operations Manager Diane Begreen and University Librarian Anna Gold implemented some of Kaelyn and Paul’s suggestions into the current design of the library (as of Fall 2021). The prime implementation of Kaelyn and Paul’s work in the current design of the library is displayed in the seating. At present, there are now tables with outlets and the capability for monitor attachment aligning the walls on the third floor of the Gordon Library. This adjustment reflects the suggestion made by the project team to recreate tech suites in the collaborative spaces since a tech suite is normally composed of a table and a monitor. The rationale for this suggestion was to maximize the usage of the tables for collaboration while reducing the bottlenecks with availability for reserved tech suites.

2.1.2 Operational Status of Higgins Laboratories

Higgins Laboratories is a three-story building adjacent to the Innovation Studio. Higgins Laboratories houses the Department of Mechanical Engineering (ME) professor’s offices, classrooms, labs for the departments of Mechanical and Aerospace Engineering, an art design studio, a low-speed wind tunnel, laser holography, manufacturing, computer-aided engineering labs, and fluid and thermal dynamics processes[27]. Extracurricular organizations such as WPI’s chapter for the Society of Automotive Engineers (SAE) utilize the workspace on the lowest floor of the building. This floor also contains some offices for robotics faculty.

Our project focuses on the basement of this faculty, a space used mainly for student projects and club activities. The space has multiple labs used by SAE, ME, robotics, and graduate students with a large amount of this workspace being taken up due to storage issues from current and past Major Qualifying Project's (MQPs) equipment[27, 29]. Currently, one of these MQP workspaces has been cleared out and the space is being redesigned into an experimentation lab where the goal of this space is to have equipment that can be moved out of this space into classrooms for demonstrations, classes can go into the room for demonstrations, and outside of class hours, students can freely use this workspace for different projects[27, 29].

2.1.2.1 Past Research in Space Optimization of Higgins Laboratories

There have been multiple attempts by other research projects, students, and staff to change the space and make the space easier to use and more accessible for students. Though, due to budgeting, and many different departments struggling with ownership of the space these projects usually do not result in any change[29]. Every department that has a space in Higgins Laboratory basement is trying to expand as the student population grows and the budget shrinks while new space is not added. Student groups such as SAE have had to move much of their equipment and workspace into off-campus locations for them to have the proper workspace[29].

One of the main projects attempted over the last couple of years has been the creation of an inventory system as a way to handle the facility's inventory and storage problems[Sal]. This project falls on the professors and project advisors that do not have the time to dedicate to a project of this scale. There are at least three separate locations dedicated to the storage of past projects and equipment causing both students and faculty not to be aware of the resources available[27, 29]. This results in a lot of duplicate equipment being purchased which is a waste of budget, time, and space. In development is a new experimental lab; there are no current floor plans for how the space will work, let alone applying Industrial Engineering principles to the space for it to function optimally[27, 29]. Due to a combination of budget and management issues no current space efficiency projects are being worked on to help the issues or future projects found in Higgins[27].

2.1.3 Operational Status of Innovation Studio

The Innovation Studio is a collaborative workspace centrally located on WPI's campus. This building houses a makerspace, a 3D printing lab, tech suites, classrooms for interactive instruction, tables for collaboration, and a long set of searchable stairs. Moreover, the Innovation Studio is typically louder than other workspaces, since it was designed to be a collaborative space and is also used as a cut-through for students to walk from one side of campus to the other. During the day, classes are held within the building, and the door to the robotics lab is often opened.

2.1.3.1 Past Research in Space Optimization of Innovation Studio

The Innovation Studio does not track the occupancy or capacity by collecting data on the number of people entering and exiting the building[2]. There is currently a student-run project that is making efforts to add an occupancy tracking system into the faculty, but this project is still in the very early stages of development and will likely not be completed in the near future[2]. The Innovation Studios acts as a selling point for prospective WPI students, and it is shown to be a high-tech collaborative space to cultivate new ideas with hands-on projects and asks as a showcase for many great projects created at WPI. Due to this, the Innovation Studios is a major stopping point on tours for these prospective students, investors, and other campus visitors[2].

2.2 Introduction to Axiomatic Design

Axiomatic Design (AD) is an approach to problem-solving that focuses on finding the best way to solve a problem by analyzing the customer needs, and using these needs to determine the functional requirements, design parameters, and process variables [Suh]. Created by Suh in the 1990s and adopted as a widely used design theory, its applications can range from mechanical or software design to manufacturing processes[Suh]. Using a mapping framework that includes identification of customer attributes (CAs), functional requirements (FRs), design parameters (DPs), to produce process variables (PVs) for the process domain [13].

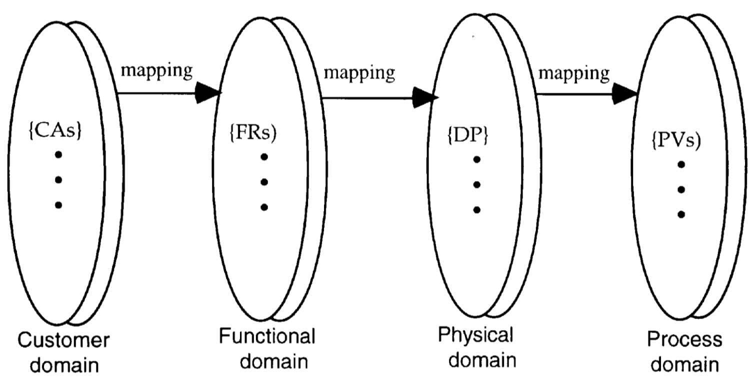


Figure 1: Axiomatic Design

Here, customer needs are defined as the desires of the stakeholders, the needs that drive them to use a space or product in a certain way. These needs are then used to help identify the FRs, the set of requirements for the system that aligns with the design goals of a system. The relationships between FRs and the DPs are then shown in a design matrix and analyzed to identify fundamental issues after being manually identified and labeled. One goal of the analysis is to decouple as many FRs as possible, coupling exists when one DP varies and it affects more than one FR, creating the *Independence Axiom* where the independence of the FRs must always be maintained [9]. Another goal is that after determining the independent axiom, the design with the smallest amount of information content is determined, and creates an *Information Axiom* [9].

The Information Axiom and the Independent Axiom worked together to achieve an overall goal of creating a basis for the design and improving the system to be simplified and efficient. When the axiomatic design is done properly this results in the proper problem definition so the correct and most important issues with the system are identified. Starting with correct problem definition means every change meant to fix the space will be targeted correctly and this will find long-term solutions for the space.

2.3 Space Optimization Techniques

Space optimization techniques are used to ensure that facilities are designed to effectively fulfill their purpose by having a layout that produces a logical flow between and within various departments. The process to make this possible often involves Systematic Layout Planning (SLP). SLP takes the inputs, flow of materials, and activity relationships to form a relationship diagram. This relationship diagram is then assessed for its space requirements and available space to determine a space relationship diagram. Once constraints are modified and practical limitations are assessed, layout alternatives can be developed and evaluated. Layout alternatives can be developed using a variety of tools, such as Relationship Charts(REL), rank order clustering, and improved algorithms.

2.3.3 Engineering Economics

Engineering economics uses mathematical methods and logic throughout many different industries including project development, design, and manufacturing systems. This method can be used as a justification for decision making within these industries. Decisions such as choosing a supplier, production styles, design styles, or understanding the impact costs throughout a system can have on other factors within the system. Some economic tools that are used in the decision making process include cost analysis, time-value of money analysis, mathematical modeling, and taking into account external costs and unexpected costs of production[25].

Chapter 3: Methods

For our Major Qualifying Project (MQP) our team used a variety of scientific and statistical tools to obtain our data. For each building our research focused on, our first step was to interview the staff associated with each respective facility. This step was paramount since the development of an axiomatic design matrix is dependent on a thorough and accurate understanding of what the customer needs as well as the functional requirements of a system. Following the interviews with faculty from each facility, we were able to use this information and other sources of information to determine the customer needs as well as the functional requirements. In the upcoming sections, we will discuss how we used interviews and other sources to determine the CNS and FRs for Gordon Library, Higgins Laboratories, and the Innovation Studio.

3.1 Gordon Library - Methods

3.1.1 Interviews with Gordon Library Faculty

During our interview with the Operations Manager and Sustainability Coordinator, as well as the University Librarian, we were given a walkthrough of the library and were updated on the changes that had occurred since the conclusion of the “Recommendation Report for Optimizing Individual Study and Collaborative Spaces on Gordon Library’s Third Floor” project. We were also given access to Gordon Library’s five-year plan of renovation, drawing of potential floorplan changes, and access to both Libcal and Sensource Data. Libcal is the software that Gordon Library and other facilities on campus use to track the usage of reservation spaces on campus. Sensource is the software that works with the sensors that Gordon Library uses to track the building’s occupancy status in real-time. Both of these software platforms were useful for analyzing the current state and developing our recommendations.

3.1.2 Determining CNs and FRs for Gordon Library

We used two main sources to determine the customer needs and functional requirements for Gordon Library. The first source came from the library staff during our interviews with the staff. We discussed in depth their goals for the space and how the space is currently used. Their knowledge comes from years of observing student activity, current research being done on the future of libraries, their space occupancy data, as well as the past surveys they have done on the student population. Most of the goals for the future of the library have been written out within their five-year plan document which they provided to the team, this document is the five-year plan they have proposed to the school that breaks down for each of the next five years what the library is planning to change, why they believe it needs to change and the financial analysis of implementing all of theses changes. Combining the ideas of the library staff and what they believe are the customer needs with our team's more current survey data that was collected and the unique perspective of the student that as a team we were able to provide we determined what we believe to be the customer needs and functional requirements of the space.

3.1.3 Distributing & Analyzing Survey for Gordon Library

To assess the space allocation for Gordon Library, our team created a survey using Google Forms to obtain student feedback. We decided to use a survey because Gordon Library has historically had success when using surveys to address customer needs. Our main points of interest in this survey were to collect data on why the students were using the space, the amount of time they spent using the space, as well as details on any barriers, such as availability, that prevented them from using the respective spaces in our case study. We then decided to use the data from these to hit two main objectives: additional insight on student needs and support for the development of our recommendations.

The survey consisted of nine questions pertaining to Gordon Library. The survey was distributed through a Facebook Post on a class page, library staff, and the program director for WPI's business school. Members of our team also distributed the survey to our peers via aliases for our respective organizations.

Although the Google Survey platform included surveys to summarize the responses, our team created additional charts to capture certain elements of the data important to our recommendations. These three additional charts included a frequency chart as well as two bar graphs depicting probabilities of resource usage. These charts will be explained more in detail in the results section.

3.2 Higgins Laboratories - Methods

3.2.1 Interviews with Higgins Laboratories Faculty

Two initial interviews were held with faculty from Higgins Laboratories. The first meeting was held with a professor in the Mechanical Engineering Department. The structure for the interview was primarily open ended to allow the professor to highlight the most important needs and functionality of the building. During this interview we walked around the basement floor of Higgins as we were explained the purpose of and utilization of each room[29]. Following this interview we were put in contact with another professor that works with students in the MQP lab[29].

The second interview was conducted with an Associate Teaching Professor in the Mechanical Engineering Department. During this interview we were shown two important spaces: the MQP lab and an open room intended to be filled with moveable machines for student usage. According to this Professor these were two of the most important spaces within Higgins basement the goal of both spaces is to promote hands-on collaborative work specifically targeted at mechanical engineering undergraduate students[27]. Both of these interviewees wanted the team to understand that there is very limited space available to the growing mechanical engineering department. The spaces are constantly changing ownership and while the mechanical engineering department attempts to keep these spaces to themselves most of the time they get split up between different departments[27, 29].

Due to this fact and many other contributing factors the ME department just like many other departments on WPIs campus are split between many different buildings causing inventory issues[27, 29]. When told of the inventory issues they have and how professors and other projects attempting to solve this inventory issue have not been successful we offered to have our team have an attempt at this problem. Both interviewees as well as another ME professor that was present seemed to be in full support of this idea[27, 29].

3.2.2 Determining CNs and FRs for Higgins Laboratories

When determining the customer needs and functional requirements for Higgins Laboratories we decided to focus on one part of the space as this is the part that would be changed the most. The new engineering experimentation lab that is going to be in this location is getting designed from the ground up and we hope that with our axiomatic design break down when designing this space the most important needs will be reached and after the space is designed few changes will have to be made. Using the information on the space provided by both interviewees, our understanding and analysis of the empty space, combined with student perspective, the CNs and FRs of the potential experimentation lab were determined.

3.3 Innovation Studio - Methods

3.3.1 Interviews with the Innovation Studio Faculty

The team held an interview with the Makerspace Advanced Technology and Prototyping Specialist to gain more of an understanding of the operations of the Innovations Studios . As the makerspace is the largest collaborative working space within the Innovation studios, the team believed this interviewee would have the best understanding on how the facility functions and the improvements it might need. The interviewee informed us of changes that have been made in the recent years due to COVID-19 including the reduction of the number of tables to allow for physical distancing, an increased use of their reservation system for collaborative space, and converting a conference space to a student study space[2]. They were also able to highlight some of the issues that the space has, some issues were previously identified by the team due to the team's student experience within the space while others were new to the team.[2]

Issues with the 3D Printers lab were identified based on the team's student experience at WPI and informal interviews and conversations with students and confirmed by the interviewee. The 3D printers are run by student workers and due to their high demand, long running time, and the problems that can occur when running the machines there is often a major backlog for the final products[2]. This fact causes problems for students as many of them are using the machines for class projects that have strict deadlines they need to meet. Other issues the interviewee discussed were the schools safety certification and training programs, there are many machines available for the entire student population to use in not just the Innovation Studios, but other campus locations including Higgins Laboratory and the Washburn Shops[2]. While many of the types of machines and training needed overlap for these places the interviewee pointed out gaps in the training because the actual type of training differs, where to get the training, and what machines each training allows a student to use[2]. This can cause many students to get confused on what machines they are allowed to use, faculty to be confused on if the students have been trained or not, and causes students to have to repeat very similar training sessions. The interviewee has suggested working with the other spaces to develop training that is more efficient for the student though there has been a lack of communication and this effort has not moved forward[2].

The effect of WPI's campus culture on student spaces has been a frequently broached topic in most of the team's interviews including our interview with faculty at the Innovation Studio[2]. The team suggested ideas such as moving some equipment around or out of the space to maybe help with the bottlenecking of space constraint issues the Innovation Studios sees and when this was discussed we were told the school would not let that happen[2]. As the Innovation Studio is used as a showcase for collaborative work and innovative technology, moving any of the equipment around might change what the building was partially intended for: large windows allowing passersby to see directly into the working space.[2] So moving any of the equipment might change that and make the space look not as attractive to anyone outside the school. Another cultural issue that was discussed was customer feedback on the space while the Innovation Studios does have forms online and a suggestions box it is not advertised for a well used system so the space receives little to no feedback[2].

3.3.2 Determining CNs and FRs for the Innovation Studio

From the team's discussion with their interviewee and the understanding of the current layout and uses of the space the customer needs and functional requirements were developed. They were developed with the goal of increasing overall workspace and availability of the space to WPI's student population. This included not just ideas of space efficiency, but with the knowledge of their current issues in mind so also reference was the space's equipment training requirements and the current space reservation systems.

Chapter 4: Results

Using the aforementioned methods, our MQP team gathered and analyzed data based on each of the spaces to develop the following results. Axiomatic design methods and an analysis of the culture were used for all the spaces and other individual methods for each space were used. For Gordon Library this included an analysis of survey data, applying and further developing past operational research done on the space, and doing an economic analysis on changes made to the space. Higgins Laboratory included follow up interviews done for the development of an inventory list. While the team hoped there could be a greater analysis done on the Innovation Studios we were unable to keep in contact with employees and obtain the level of data needed for an appropriate analysis.

4.1 Gordon Library - Results

4.1.1 Gordon Library Axiomatic Design Decomposition & Matrix Analysis

Our Axiomatic Design Decomposition for the library consisted of four main functional requirements and four corresponding design parameters. The four main function requirements for the library were to:

- Optimize student seating space and accessibility of Gordon Library
- Minimize services oversight
- Increase library seating space
- Manage the quality of seating space

The first requirement contained four sub-functional requirements intended to support the development of the main requirement. These sub functional requirements included:

- Determining which rooms were critical control points
- Determining services that are critical to students
- Evaluating tech suite utilization data in Gordon Library
- Collect service accessibility data from students
- Collect occupancy data for library spaces

As shown by the aforementioned sub-functional requirements, understanding the current utilization of Gordon Library's resources was essential to later identifying bottlenecks and potential inefficiencies in the system. The corresponding design parameters to these sub requirements were developed by analyzing Sensource Data, the library's occupancy tracker, as well as Libcal data, the library's tracker for tech suite usage. To confirm that the students were able to access these resources we used the data from our own survey as well as past surveys. The results of the survey we distributed will be discussed in section 4.1.2

The second requirement contained three sub-functional requirements. These three requirements included:

- Automate tech-suite reservation data collection and interpretation system
- Automate tech suite reservation system
- Automate library occupancy data collection and interpretation system

These sub requirements focused on increasing system efficiency with automation. In addition to increasing efficiency these sub requirements were intended to increase the accuracy in obtaining system functionality to evaluate the system's performance. The corresponding design parameters to these sub FRs were Libcal, WPI card access, and the people counter/video sensor.

The third requirement contained five sub functional requirements. These sub functional requirements include:

- Create and maintain a clean and orderly working environment
- Remove unnecessary physical items from hallways and rooms
- Prevent under usage of library seating space
- Evaluate headcount library data
- Achieve one piece flow with tech suite utilization

The corresponding design parameters to these sub functional requirements were

- Physical & digital instruction signs regarding workplace cleanup
- Unused tech suite reservation space
- Instructional signs that mandate the minimum amount of people required
- Excel and graphing software
- Key card reader integrated with Libcal

Additionally, these design parameters were developed to ensure that the seating space is being increased from the top down. Once the seating space is designed more efficiently, it is important to make sure that the space is being used for its intended purpose. An example of this concerns the creation of instructional signs that mandate the minimum amount of people required. Kaelyn and Paul's report highlighted a pattern of one student solely occupying a table intended for a group. This behavior automatically reduces the original seating space at this table because students are less likely to sit at a group table with an individual using this table for individual study. Thus, this action can reduce a table that originally seats 8 to just 1, making all efficiency efforts obsolete.

The final functional requirement for the library had three sub functional requirements. These requirements include:

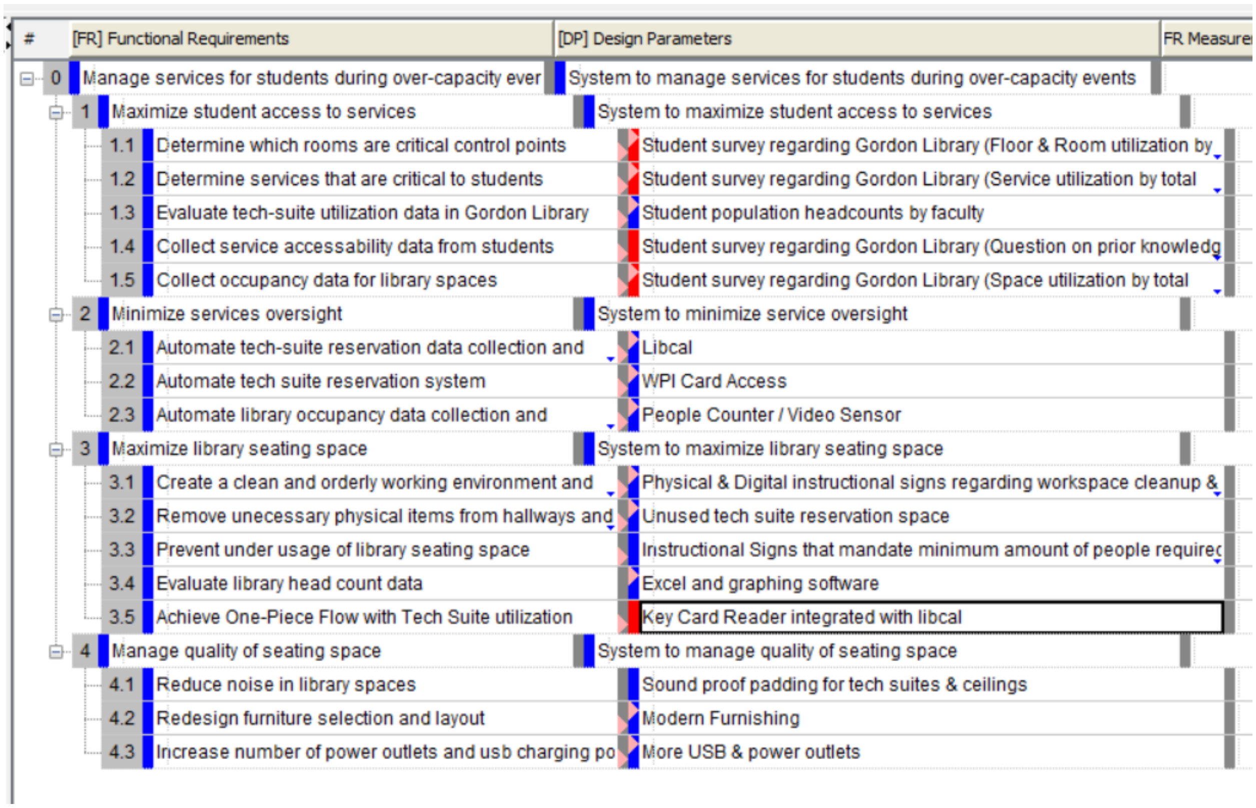
- Reduce noise in library spaces
- Redesign furniture selection and layout
- Increase number of power outlets and USB charging ports

The corresponding design parameters for these requirements included:

- Soundproof padding for tech suites and ceilings
- Modern furnishings

- More usb and power outlets

These design parameters were meant to supplement the creation of a quality space by focusing on student defined attributes that make a space ideal for studying. This decomposion is shown in figure 2, using Acclaro software.



#	[FR] Functional Requirements	[DP] Design Parameters	FR Measure
0	Manage services for students during over-capacity ever	System to manage services for students during over-capacity events	
1	Maximize student access to services	System to maximize student access to services	
1.1	Determine which rooms are critical control points	Student survey regarding Gordon Library (Floor & Room utilization by	
1.2	Determine services that are critical to students	Student survey regarding Gordon Library (Service utilization by total	
1.3	Evaluate tech-suite utilization data in Gordon Library	Student population headcounts by faculty	
1.4	Collect service accessability data from students	Student survey regarding Gordon Library (Question on prior knowledg	
1.5	Collect occupancy data for library spaces	Student survey regarding Gordon Library (Space utilization by total	
2	Minimize services oversight	System to minimize service oversight	
2.1	Automate tech-suite reservation data collection and	Libcal	
2.2	Automate tech suite reservation system	WPI Card Access	
2.3	Automate library occupancy data collection and	People Counter / Video Sensor	
3	Maximize library seating space	System to maximize library seating space	
3.1	Create a clean and orderly working environment and	Physical & Digital instructional signs regarding workspace cleanup &	
3.2	Remove unecessary physical items from hallways and	Unused tech suite reservation space	
3.3	Prevent under usage of library seating space	Instructional Signs that mandate minimum amount of people requirec	
3.4	Evaluate library head count data	Excel and graphing software	
3.5	Achieve One-Piece Flow with Tech Suite utilization	Key Card Reader integrated with libcal	
4	Manage quality of seating space	System to manage quality of seating space	
4.1	Reduce noise in library spaces	Sound proof padding for tech suites & ceilings	
4.2	Redesign furniture selection and layout	Modern Furnishing	
4.3	Increase number of power outlets and usb charging po	More USB & power outlets	

Figure 2: Gordon Library FR-DP Decomposition

4.1.1.1 Coupling Matrix

The resulting design matrix represents a best case "uncoupled" scenario in which each design parameter only influences one functional requirement. In this "uncoupled" scenario, any order of adjustment works equally well. However, this iteration of our design matrix does not accurately represent interactions or "coupling" between different design parameters and functional requirements. Interactions, based on information gathered during interviews, were then added to our design matrix and then decomposed utiling Acclaro's built in decomposition function. The result is a "decoupled" design matrix that includes interactions with a singular, optimal order of adjustments, shown in figure 3. According to our final design matrix, the optimal order of design parameter adjustments for Gordon library is as follows:

- Student survey regarding Gordon Library (Floor & Room utilization by total student population)
- Student survey regarding Gordon Library (Service utilization by total student population)
- Gordon Library student population headcounts by faculty

- Student survey regarding Gordon Library (Space utilization by total student population)
- Libcal
- Physical & Digital instructional signs regarding workspace cleanup & maintenance
- Unused techsuite reservation space

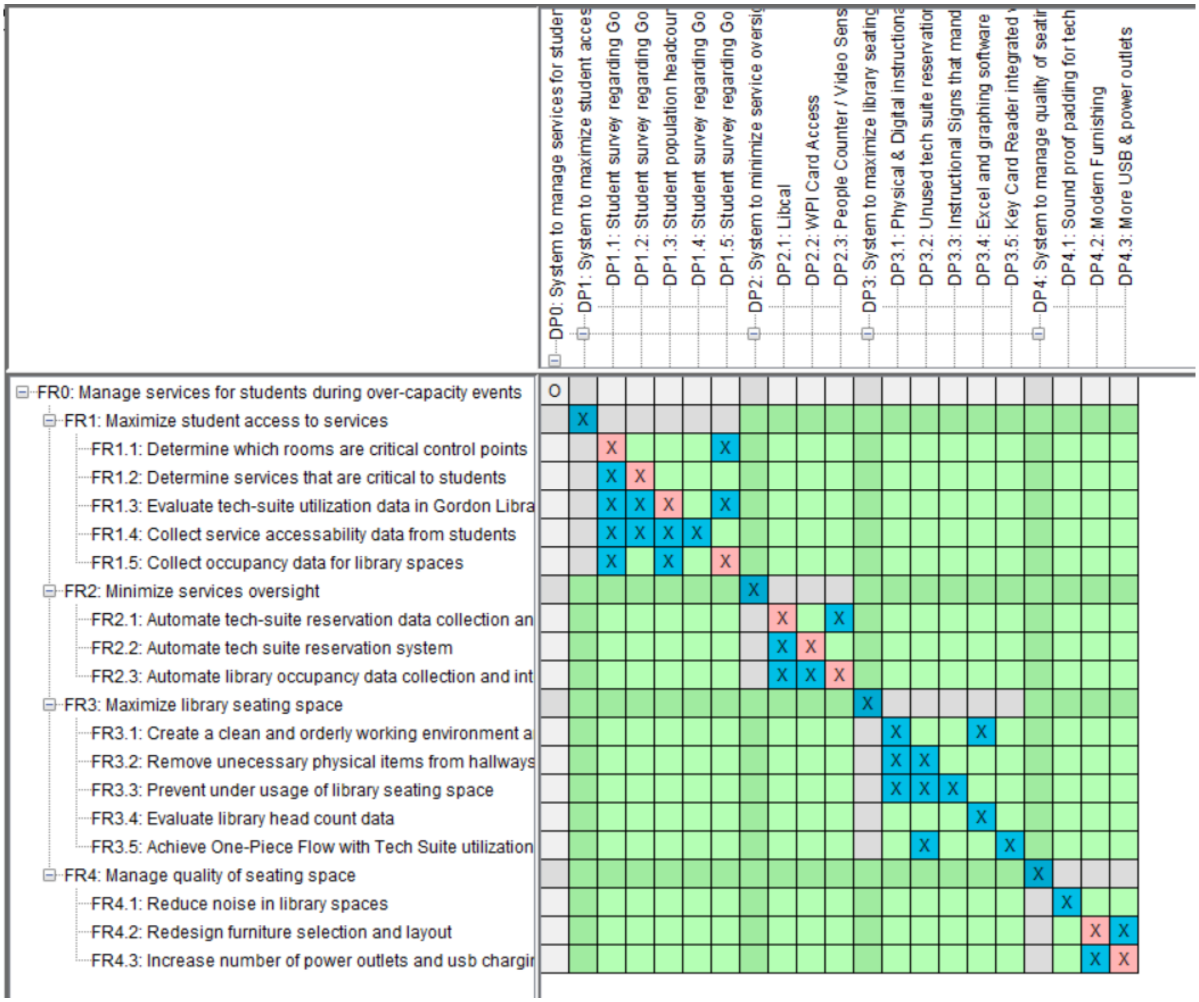


Figure 3: Gordon Library Axiomatic Design Matrix

4.1.2 Survey Data Analysis

Our survey received 91 responses. The highest number of responses came from the classes of 2024 and 2022.

40.7% of students indicated that they prefer to go to the third floor as a response to a question asking which floor they prefer to go to when visiting the library. The second most popular choice was the first floor with 24.2% of students preferring to work on this floor, and the basement was favored by 22% of students. The least preferred floor was the second floor, with 13% of students indicating that they tend to visit this floor most often. The pie chart in figure 4 displays the aforementioned data.

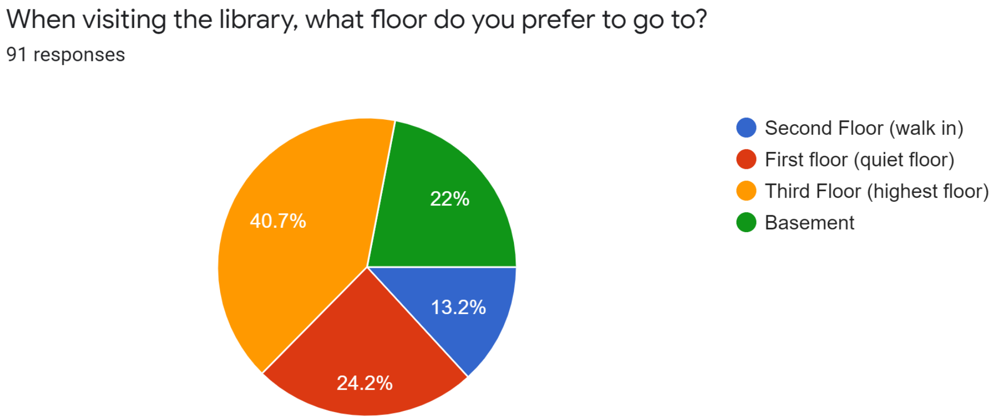


Figure 4: Library Survey Floor Pie Chart

Students were prompted to explain why they chose the particular floor they selected in the first question. Since the free response questions varied in descriptors, length, and reasons, our team categorized the responses into key phrases to see the most common attributes that made a floor more appealing to students. These attributes were space, volume, collaboration, convenience, environment, focus, and resources. A response was categorized as a space attribute if it had key words and phrases such as “space”, “spacious”, “more”, or “big enough”. Responses that fell under the volume category contained words such as “quiet”, “loud”, or “noise”. Similarly, responses relating to collaboration attributes referenced words like “team”, “group” or “collaborate”. Some responses fell into the category of convenience, with students mentioning that they mainly visited a floor because it was the “easiest” or most “convenient” floor to visit at that time. Environmental attributes in a response indicated that certain elements of a floor’s resources such as “comfort” or “lighting” influenced the floor’s appeal. Other responses indicated that their selection of floors is dependent on their ability to “focus” or “get work done”. Finally, responses that highlighted that a floor’s resources made it appealing mentioned specific resources, such as “computers”, “white boards”, “tables”, “outlets”, or “tech suites”. To account for all data, some responses were double counted since they highlighted multiple attributes.

The data showed that volume is the leading factor that prompts students to work on a particular floor. 36 responses mentioned volume. The majority of students in this category mentioned that they prefer a quiet floor for working or that they “don’t mind the noise” because they want to be able to “talk”. The second leading factor that made a floor more appealing, according to the data, was space, which accounted for 20 responses. Some responses in this category indicated that students prefer an “open space”, “lots of tables”, the ability to “spread your work”, and “multiple seats”. Resources was the third most popular attribute. 17 responses in this category mentioned that students want to be closer to resources such as “computers”, “printners”, “outlets”, and/or “tech suites”. The attribute that was the least important in selecting a floor, according to the data, was focus. Only 5 responses mentioned the ability to focus as an important attribute to a floor. The frequency chart in figure 5 references the full distribution of data.

Frequency of Attributes Mentioned in Survey's Short Answer Section

Attribute	Number of Responses (Frequency)
Volume	36
Space	20
Resources	17
Collaboration	16
Convenience	6
Environment	6
Focus	5

Figure 5: Frequency of Attributes

The next question on the survey asked how many times on average do students use the tech suites, individual desks, "Dogbone" tables, rectangular tables, and technology during a term. Students were prompted to select if they never use a resource, use it 1-5 times, or more than five times during a term. Students were most likely to use the rectangular tables and individual desks more than five times in a term, in coherence with the data. On the other hand, students were most likely to never use the "Dogbone" tables more than five times in a term. Additionally, "Dogbone" tables had the highest number of responses (47) in the category of students saying that they never use the resource in a term. Rectangular tables, tech suites, and the computers were the most common resources to be used 1-5 times during a term. Figure 6 displays the aforementioned data

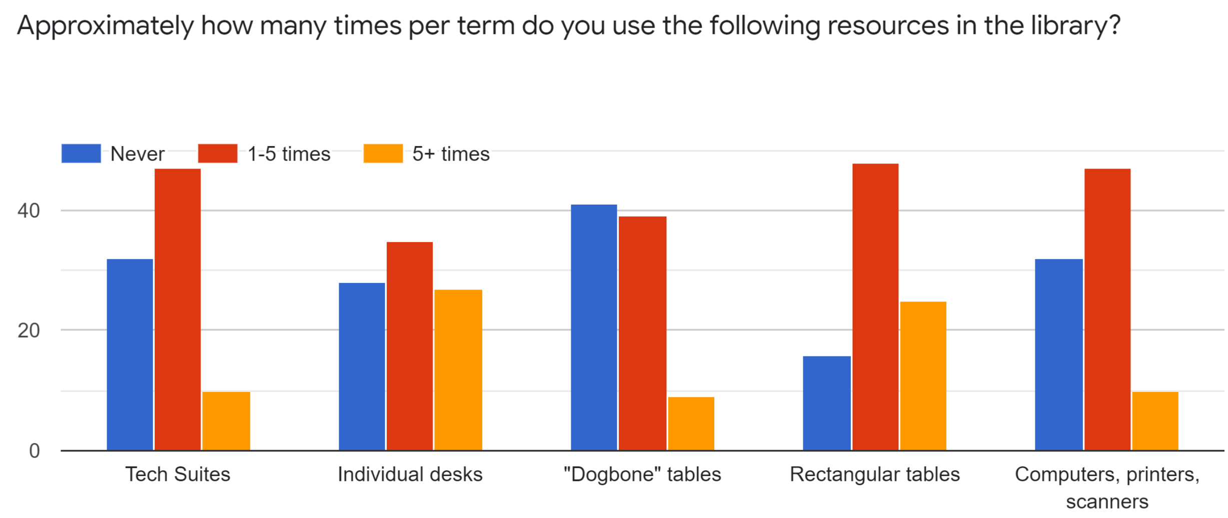


Figure 6: Library Survey Bar Chart

Since our team was most interested in the utilization efficiency of resources in the library, we further analyzed the data to see which resources are being used the most and least frequently compared to the total number of responses chosen for each category. There were 149 responses in the never category, 208 in the 1-5 category, and 81 in the more than 5 times category. The number that each resource had in the aforementioned categories was divided by the total number of resources in a category, so the representation a specific resource had in a category could be represented as a percent. We separated the analysis into the chances that a resource had of never being utilized as well as a chart comparing the chance that a resource had of being utilized 1-5 and more than 5 times during a term.

After analyzing the 149 responses that indicated a particular resource was never used, we were able to draw a major conclusion. From the data, we observed that the Dog Bone Tables have the highest chance of not being used during a term, whereas the rectangular tables have the lowest chance of not being used in a term. This alone does not mean that the Dog Bone tables are not needed; however, it does highlight that this resource may not be as essential to students as the rectangular tables. The tech suites as well as the computers, printers, and scanners, had an equal chance of not being used, and the . With these trends from this data set, we can observe that the resources arranged from most to least essential are the rectangular tables, individual desks, and the Dog Bone tables. The tech suites, computers, printers, and scanners, could be arranged in any order following the individual desks since these resources had equal percentages. Figure 7 displays this data by graphing the chance that a resource has of never being used in a term.

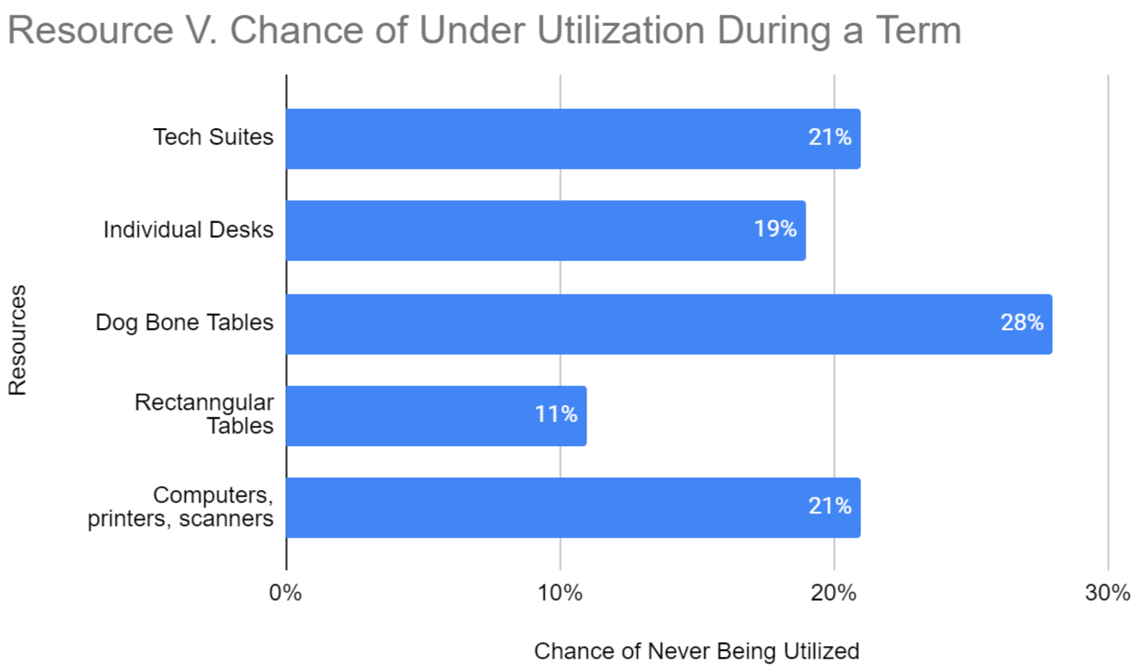


Figure 7: Library Survey Under Utilization Chart

208 responses were received in the category for using a resource 1-5 times during a term. Out of these 208 responses, tech suites, rectangular tables, and computers, printers, and scanners had the highest chance of being utilized 1-5 times during a term. The resource that had the lowest chance of being used 1-5 times a term was the Dog Bone Tables. This data, represented by figure 8 displays that the Dog Bone tables are the least essential in this category as well.

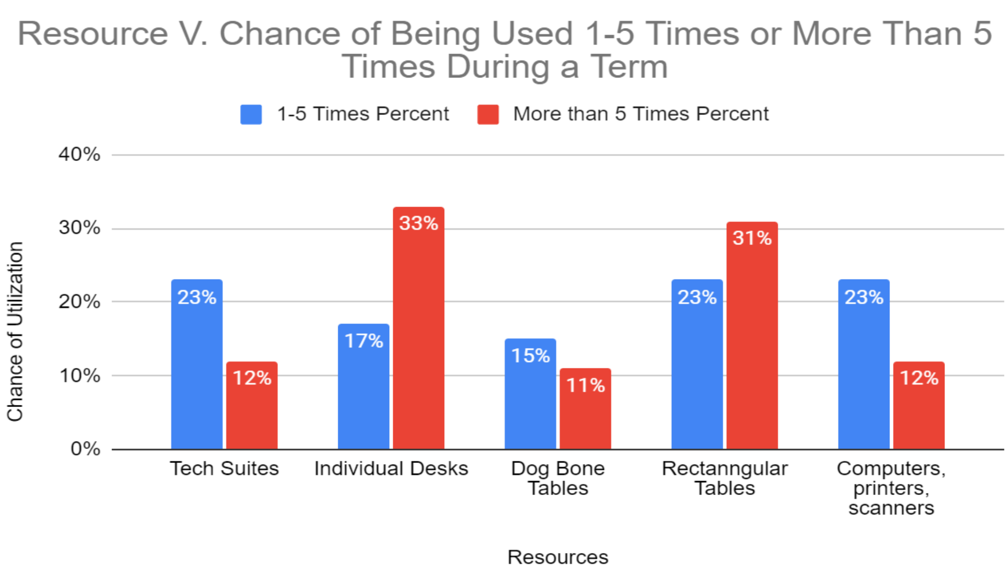


Figure 8: Library Survey Resource Utilization Chart 1

81 responses were received in the category for using a resource more than 5 times in a term. The resource that had the highest chance of being used more than 5 times in a term was the individual desks, with a chance of 33% utilization. The rectangular tables had the second highest chance of being used more than five times a term, with a percent utilization of 31%. The resource that had the lowest chance of utilization 1-5 times a term was the Dog Bone tables.

To make an overall assessment of the utilization of resources during a term, we summed the percentages each resource had from the categories of utilization 1-5 times during a term and more than 5 times a term. This new analysis took the cumulative percentages for each resource into account to see the chance that a resource had of being used at least once during a term. As expected, these results supported the previous findings from the smaller percent utilization comparisons, and made the utilization comparisons more apparent. From this data, the rectangular tables had the highest chance of being used at least once during a term, with a percent utilization of 54%. The percentage utilization for the individual desks . Figure 9 summarizes the aforementioned data.

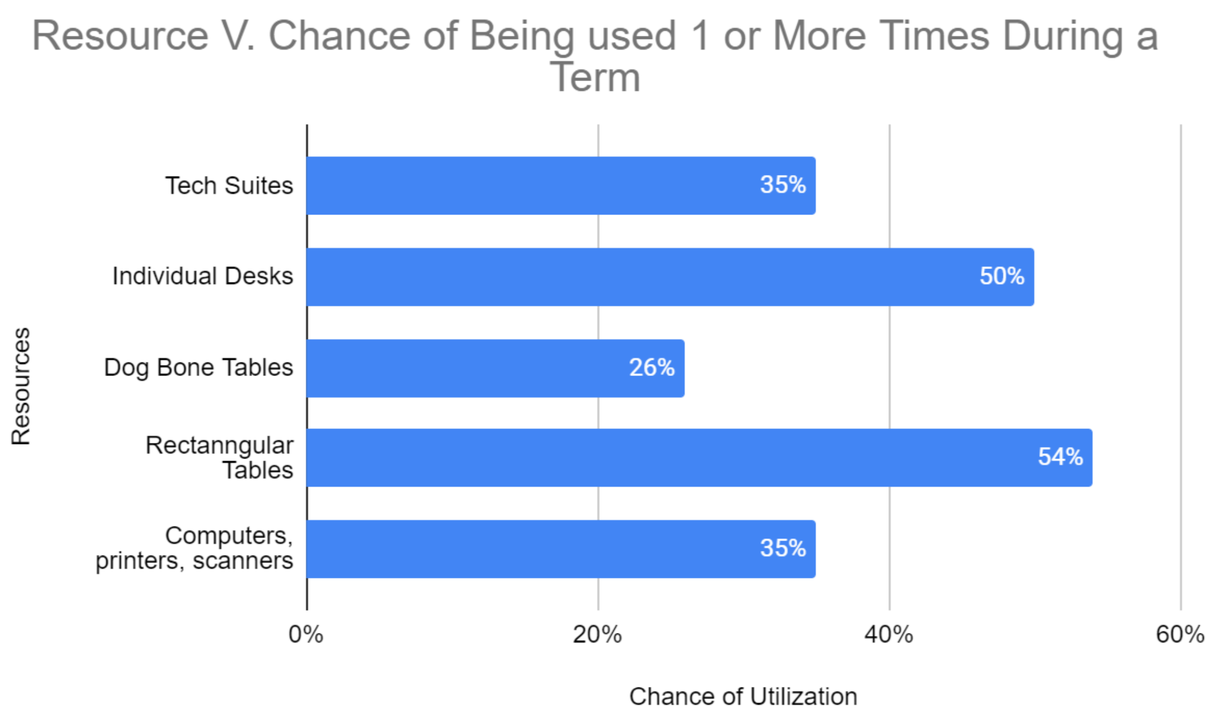


Figure 9: Library Survey Resource Utilization Chart 2

The next question on the survey focused on student's reasons for being in the library. Of the options given, the top reasons students chose to visit the library were due to collaborating and completing work individually. These reasons support our earlier findings of the rectangular tables and individual desks being the most utilized resources. Here, collaboration is also the main reason students visit the library. Figure 10 shows the common reason why students were using the space in the library. The main reasons for students using the library were very obvious. Students were mainly using the library to do work on their own or work with a group. Not many students were using the library space other than those reasons. The figure shows that a lot of the space is being underutilized due to

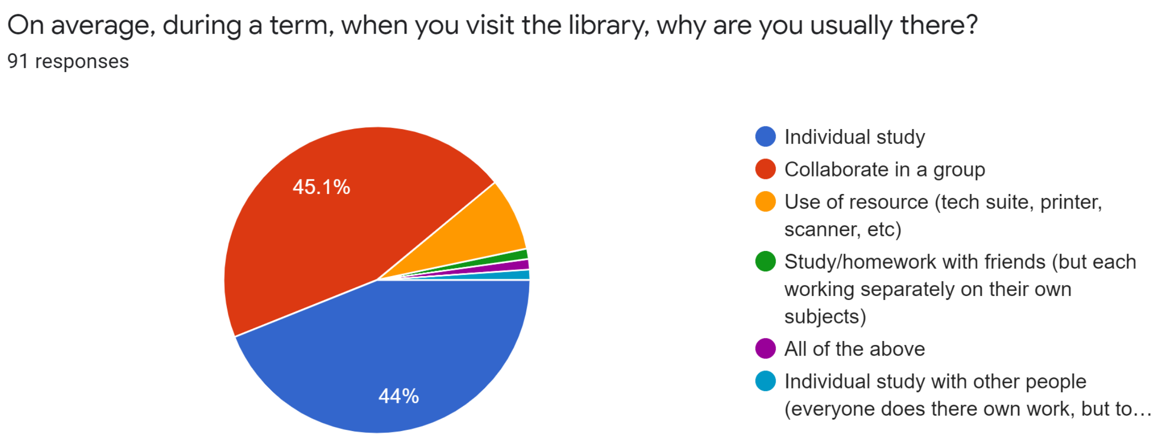


Figure 10: Library Survey Space Usage Pie Chart

4.1.3 Key Findings from Past Research in Gordon Library

4.1.3.1 2018 Initial Gordon Library Report

In 2018 Gordon Library produced a report intended to obtain feedback on how and why students use the library. Additionally, this report was developed to gather information on what students believe the library is doing well, areas of improvement, and student priorities on space, services, and resource utilization. This survey was distributed in D term of 2018 (March - May) using Qualtrics. 958 students participated in this survey. For our research, we were primarily interested in the data focused on building usage, student priorities for the library's improvements, and students' feelings toward the library.

Our first area of focus was building usage. In the report, students were prompted to indicate the frequency at which they visit the library. The options were "weekly", "monthly", or "rarely/never". 956 students responded to this question, with 78.77% of students visiting the library weekly, 12.03% of students visiting the library monthly, and the remaining 9.21% of students rarely or never visiting the library. Here, we can see that a large majority of students visit the library weekly. Another question in the report prompted students to indicate if and how they use a variety of spaces in the library. The results from the report indicated that the tech suites, the FLIP space (on the third floor of Gordon Library), and the quiet floor were the destinations for students who intended to study in Gordon Library. The Fellman Dickens Reading Room, the Multimedia Lab, and the Library cafe, on the other hand, were the top resources that were not used. Figure 11 shows the full data for resource usage from the report.

#		Study		Find Info		Use Software/ Hardware		Non-academic purposes		I Don't Use		Total
1	Tech Suites	75.78%	898	3.29%	39	5.91%	70	5.65%	67	9.37%	111	1185
2	Quiet spaces (1st floor)	64.67%	723	3.94%	44	3.85%	43	3.94%	44	23.61%	264	1118
3	Tables outside Cafe	49.78%	672	4.96%	67	9.93%	134	9.19%	124	26.15%	353	1350
4	Cubicles	59.55%	611	2.92%	30	2.34%	24	2.34%	24	32.85%	337	1026
5	Library cafe	28.17%	304	0.74%	8	0.46%	5	36.89%	398	33.73%	364	1079
6	Fellman Dickens Reading Room	8.03%	74	4.56%	42	0.33%	3	2.50%	23	84.58%	779	921
7	FLIP Space	70.56%	856	1.81%	22	1.24%	15	4.04%	49	22.34%	271	1213
8	Multimedia Lab	29.42%	323	4.46%	49	14.03%	154	1.55%	17	50.55%	555	1098
9	Studio@Gordon	56.38%	698	1.70%	21	1.94%	24	6.30%	78	33.68%	417	1238

Figure 11: Resource Usage Data

Our second area of focus from Gordon Library's 2018 Report was the student priorities for the library's improvements. The survey provided students with a list of 12 potential improvements to the library facility. Students were asked to indicate how important the potential improvement was to them by selecting "important' or "very important". In accordance with the report's results, the top five choices that students considered important were more "power outlets" (56%), "more tech suites" (47%), "more group study spaces" (47%), and "more individual study spaces" (40%). "More soft seating" and "more/better whiteboards"' were tied with 39% respectively. Similarly, the survey prompted students to answer the free text response question: "what is the top change Gordon Library could make to better suit your needs?" In accordance with the report, of the 648 students who answered this question, 396 students discussed the lack of space or their desire for more space. More specifically, responses that centered on space mentioned "more group space" (80), "more tables" (73), more seating overall

(60), “more individual study spaces”, “more cubicles” (22), and “more workspace in general” (22).

Our final area focus from Gordon Library’s 2018 report was on students' feelings about the library. The survey prompted students to choose five words from a list that best described Gordon Library. In coherence with the survey, the top five words selected included “welcome” (639), “safe” (598), “calm”(582), “satisfied” (548), and “relaxed” (528).

4.1.3.2 2019 Student Recommendation Report

As discussed in section 3, our team analyzed the findings from a 2019 student report titled “Recommendation Report for Optimizing Individual Study and Collaborative Space on Gordon Library’s Third Floor.” Although the report, developed by Kaelyn Hicks and Paul Pacheco, primarily focused on the third floor of the library, we were able to retrieve information that paralleled the methods used in our own study.

The first finding concerned volume. Hicks and Pacheco’s report found that the majority of students (68%) who participated in the study preferred a “somewhat conversational” environment while studying. 27% of students preferred a “completely silent” environment and 4.5% of students highlighted that they prefer a “conversational” environment while studying. A similar question, in the report, asked students the volume that they prefer when collaborating. The three options available were “slightly noisy”, “somewhat conversational”, and “conversational’. 68% of students highlighted that they prefer a “conversational” environment, 31.5% preferred a “somewhat conversational” environment, and 7.2% of respondents highlighted that they prefer a “slightly noisy” environment. Thus, the trends from this finding revealed that the majority of students prefer a “somewhat conversational” environment while studying and a “conversational” environment while collaborating.

The second area of focus was on space utilization. The survey in the report asked students to select “yes” if they were happy with the workspace on the third floor of the library, or “no” if they weren’t happy. 49.5% of students selected “yes” and 50.5% of students selected “no”. Students who selected yes were invited to share features of the third floor that they liked. Of the 55 students who selected “yes”, 45 students provided short answers discussing aspects that they liked about the third floor. The main topics that were mentioned in the survey were tables, whiteboards, volume, and computers. Figure 12 displays a chart from the report that displays the frequency of key resources mentioned in the short responses of students who selected “yes”.

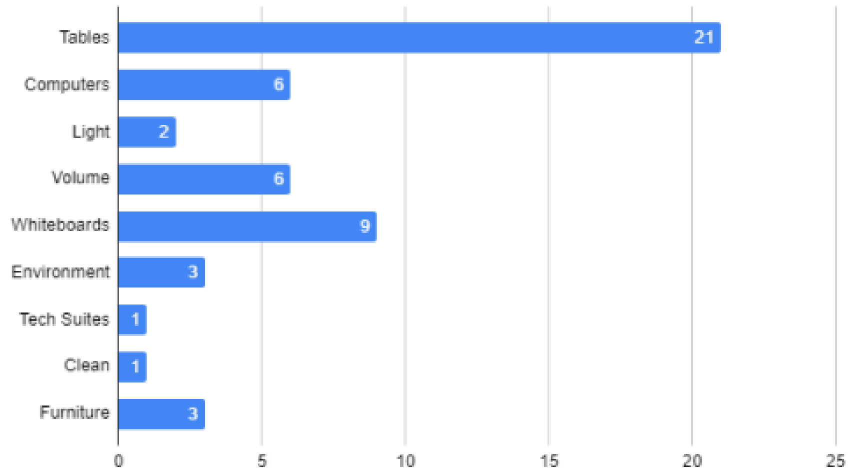


Figure 12: Library Survey Frequency Resources Mentioned

On the other hand, students who selected that they were not happy with the workspace on the third floor were invited to suggest ways to improve their experience while working on the third floor. Of the 56 students who selected "no", 53 students provided short responses prompting improvements. The majority of responses in this category highlighted a desire for "more tables/seating", improvements to "space/organization" and "computers/technology". Figure 13 displays the improvements that were most frequently mentioned by students who selected "no".

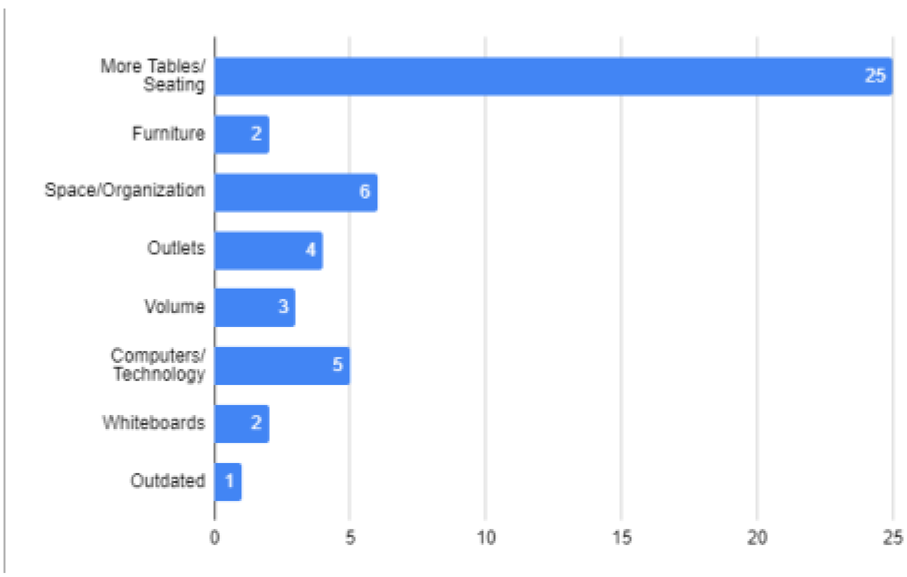


Figure 13: Library Survey Improvement Mentioned

4.1.4 Engineering Economics

In order to provide a justification to Gordon Library's five-year plan renovation costs we provided an engineering economic analysis based on student and renovation costs. Based on WPI's website, each student pays WPI approximately $31,432 in tuition and another $10,450 in living/school supply expenses each year. According to a standard course load for a student, 6 classes per term, along with the expected study hours; WPI believes a student should be putting in a student on average spends 5712 hours either in class or working on class material per year. This equates to a value of approximately $7.33 per hour of study time for each student to be at WPI.

According to the Gordon Library's five-year plan, there is a proposed expansion to the capacity in the library. The primary goal of said expansion is to add 230 seats to the library at an estimated cost of $2,273,000. In a cost/benefit analysis of this expansion, the value of a student's time is equated to the value of each additional chair being added per hour. Under the assumption that if a student is spending time in a study space such as the library the profit of the student is going to that study space.

$$230\,seats\ *\ \$7.33/hour\ =\ \$1686/hour$$
$$18\,hours\ *\ \$1686/hour\ =\ \$30349/weekday$$
$$17\,hours\ *\ \$1686/hour\ =\ \$28663/weekend\ day$$

$$\$30349/weekday\ *\ 5\ +\ \$28663/weekend\ day * 2 = \$209071/\text{week}$$

Based on the above equations each week there is a total added benefit of $209,071, meaning that if the library's added sections are always at full capacity the total time to pay off the initial investment is about 11 weeks. For a more accurate representation of a break even point for the library we calculated if throughout the week there was only an average of 25% of the added seats being used with an inflation rate added each month of 2% to represent the increasing cost of tuition which in turn increases the value of a student's time. Assuming only 25% of the seats are being used, then the total time to pay off the initial investment is 43.49 school weeks, just about 11 months, shown in figure 14.

A breakeven chart is used to compare the cost of an investment to the earnings based on the investment over time, with the earnings over time changing based on an inflation rate that the real-world problem would be facing. Representing over time how the investment will be paid off, therefore helping to make decisions on if investments would be worth it, if the increased profit/efficiency is worth the cost of changing or adding the improvements. In Gordon Library's cases as discussed above, this is represented by the value of a student's time being the added profit and the cost of the renovations being made as the investment. Under these assumptions the cost of renovations seems worth it for the added value as the renovations according to the library will happen over five years and take less than a year to pay off, a added value that they will continuously benefit from for many years that will also benefit the student experience

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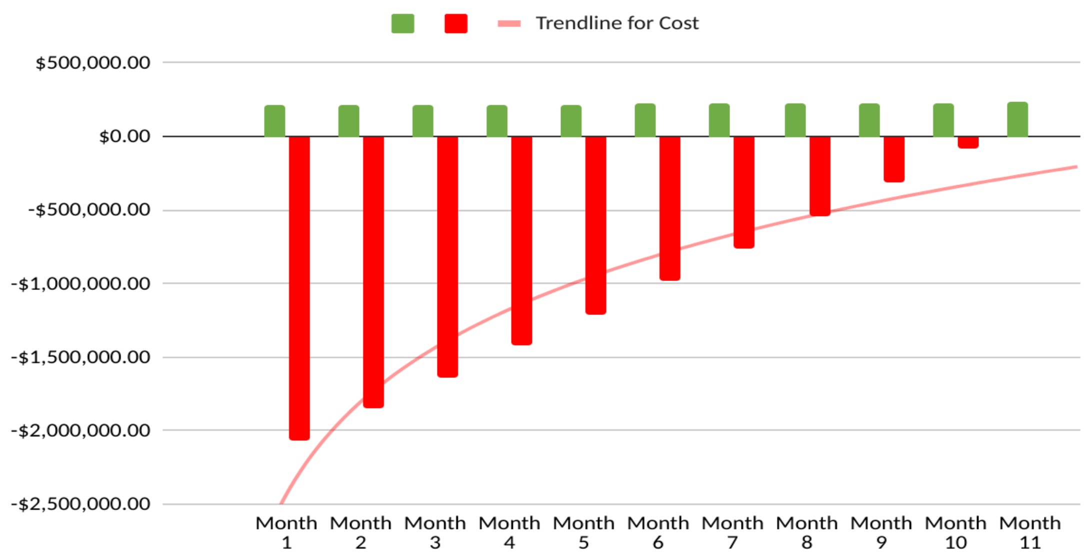

Figure 14: Break Even Analysis

4.1.5 Culture Analysis

Gordon Library's workers have always had a culture of continuous improvement as they are a student oriented space working to change with the times and provide the resources students need. Shown in another interview the team conducted with a past WPI library employee, who told the team of past improvements made to WPI's library including the development of the current model of the tech suites which are now used around WPI's entire campus[27]. Due to this fact and the libraries already in progress efforts to make changes to the space the staff that the team was in contact with was more than willing to continue meeting with us throughout our project and willing to provide data and take feedback on any current plans they had. The changes the library has and will continue to make have always been focused on the students, their customers, which is why many of their changes work and are executed properly[16]. These changes are focused in how the space is designed, the technology that is being added into the space and the filtering out of old and unused resources such as journals that have become more available digitally so there is less of a need for the physical resources. All of these changes align with needs shown in the axiomatic design decomposition the team did which were mainly based on student survey data showing that the library has functional requirements and customer needs driving their changes.

4.2 Higgins Laboratories - Results

4.2.1 Higgins Laboratories Axiomatic Design Decomposition & Matrix Analysis

Our axiomatic design for the Higgins Laboratory was based around a singular lab room. Our top-level functional requirement (FR0), was to create a dynamic floor plan. This top-level FR consisted of 7 other upper-level functional requirements:

- FR1 Determine critical equipment restraints
- FR2 Create a clean and orderly working environment
- FR3 Prevent under usage of physical workshop/lab spaces
- FR4 Create room for project workspaces
- FR5 Create clear, clean paths within the room using the minimum space required for moving equipment
- FR6 Create an Inventory System
- FR7 Achieve One-Piece Flow with workshop and lab space (students = product).

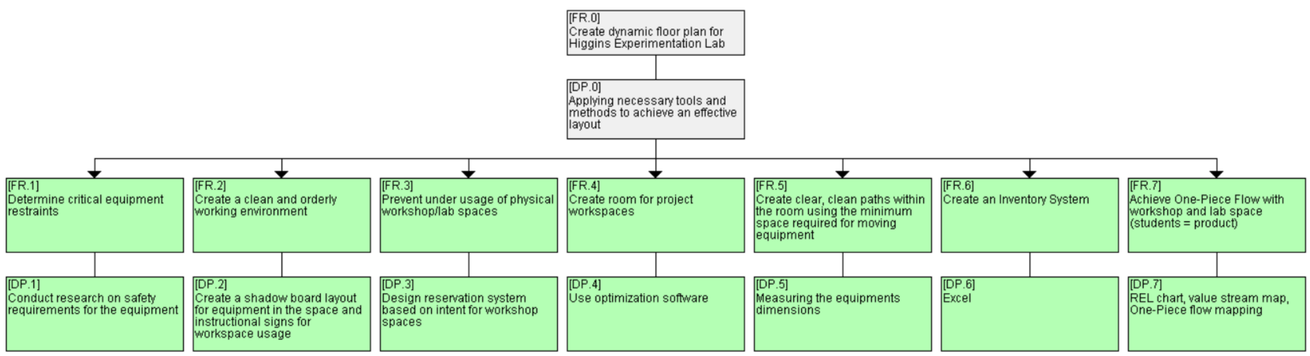

Figure 15:Higgins Laboratories FR-DP Decomposition Tree

We based our functional requirements and design parameters around the fact that we were only given a small lab space to work with and redesign, the relationship of FRs to DPs are shown in figure 15 the decomposition tree. The parameters and key details behind running an efficient lab space were addressed in the axiomatic design. A big issue with the lab space in Higgins was that there was no clear functionality or flow to the system. A lot of the time students using the space would not log their time in the room. Ledding to a lot of confusion between students regarding when the actual lab space was open and free to use.

While we wanted our functional requirements and design parameters to address the issues of room flow and use, we also wanted to address the cleanliness and organization of the lab room. Our focus was on increasing the student traffic within the lab space. While also creating a clean and productive thinking space for the students to work in. However, more development and understanding of the space's axiomatic design was unable to be done because the intended use of the space has been constantly changing. While initially we were told the space would be a dedicated Mechanical Engineering experimentation lab the team was later informed that the space is now being divided between multiple different departments. Due to this the team was also never provided a list of equipment that will be within this space as this along with its utilization has been constantly changing[27, 29].

4.2.1 Culture Analysis

Many of the cultural issues that Higgins laboratory is facing are repeated throughout much of WPI's campus with the dramatic growth the Mechanical Engineering department has experienced in the most recent years without expanding space dedicated to the department. This in combination with other departments also growing and trying to expand space has put a major strain on all departments. More and more spaces that were previously dedicated to Mechanical Engineering are now being split between multiple departments, or being fully taken away from ME. Seen with the experimentation lab that is being developed, due to the lack of control over their own space there is not a strong driving force for change. The department has experienced multiple times making plans for change and not being able to execute them due to the reallocation of space. This is also leading to unorganization of equipment within the department as all their equipment is being spread through many different campus locations. Without any organizational patterns and without the support of both the school and the ME department this caused the team to run into many problems when trying to explore and investigate issues. Information necessary to our project was unable to be provided to the team, not allowing us to fully develop solutions to the issues the department has been facing. Due to this recommendations to the space are being made with the focus being on the student experience of the space.

4.3 Innovation Studio - Results

4.3.1 Innovation Studio Axiomatic Design Decomposition & Matrix Analysis

For the Innovation studios we decided that our FR0 would be to "Maximize usage of collaborative workspace within the Innovation Studios" These collaborative spaces are spaces like the makerspace, 3D printing lab, and the robotics garage. We wanted to first address the under usage and over usage of some of these spaces. Which is why our first functional requirement was based around the idea of maximizing the space to allow the most student traffic at various student study spots within the building.

- FR1: Maximize available student workspaces
    - FR1.1: Determine peak times of use of workspace
    - FR1.2: Determine commonly used areas, workspaces, and furniture

For the second requirement we wanted to address the bottlenecks that occur at various student building spaces. We wanted the functional requirement to address the lack of space traffic control and services that were deemed popular amongst the student population. This set of functional requirements sought to minimize overload and underload of the makerspaces.

- FR2: Maximize students access to 3D printing and makerspace services
    - FR2.1: Determine services that are critical to students
    - FR2.2: Ensure services are accessible in student over-capacity scenarios.

For the third requirement we decided that a uniform training system was direly needed due to lots of miscommunication across campus. Due to the fact that the skills training is different depending on where a student may get that training. This unification of training systems would help the traffic of students using machines to be spread across the campus to other machine shops and not just the centralized spaces; like the Washburn shops.

- FR3: Unify training management systems
    - FR3.1: Create a uniform training system that is standardized across campus
    - FR3.2: Ensure all training is being taught the same way

For the fourth requirement we focused on the aesthetic and practicality of the student spaces from a physical perspective. This functional requirement was one that sought to keep a clean and organized look of the spaces within the Innovation studios. This FR also sought to spread out the traffic of students by reorganizing the space based upon tool/space popularity and usage.

- FR4: Provide a clean and orderly work environment
    - FR4.1: Remove unnecessary physical items
    - FR4.2: Reorganizing popular items/objects on floor space

Lastly, our final FR addressed space in the building that was being used significantly less than the others. In order to maximize the building's usage, it was important to make sure that students were aware of the other spaces that could be used. And also so that they could take advantage of the open space at all times. A representation of all the FRs and how they relate to the space's DPs are shown in figure 16 with a decomposition tree.

- FR5: Minimize under usage of physical study spaces
    - FR5.1: Promote the use of spaces available
    - FR5.2: Interchangeable spaces from individual to group study spaces

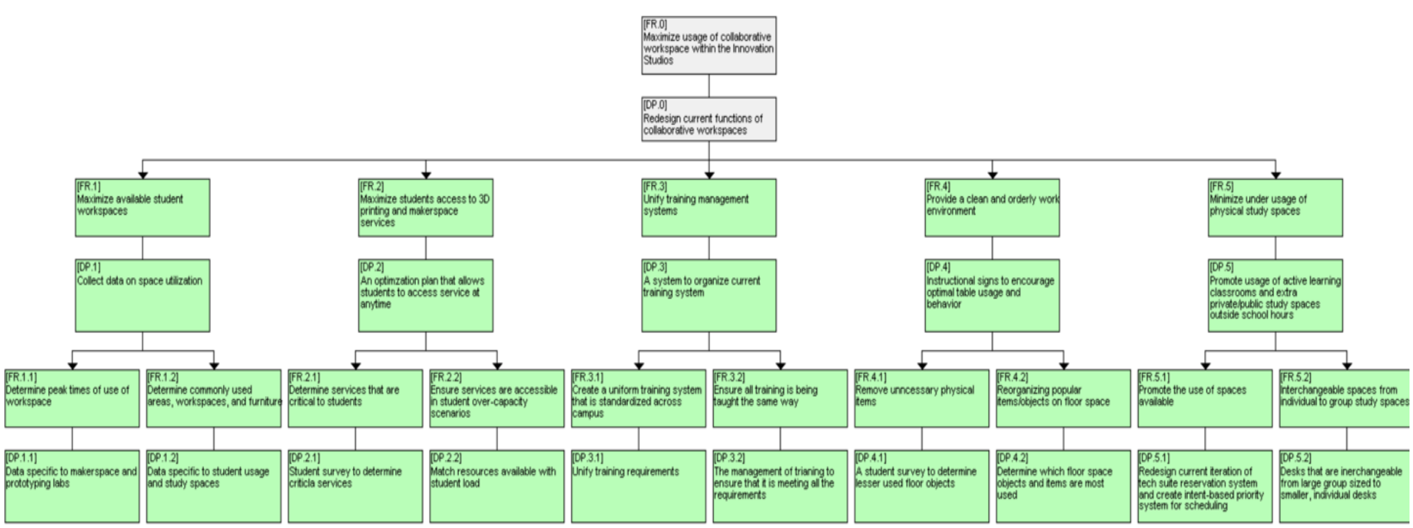

Figure 16: Innovation Studios FR-DP Decomposition Tree

4.3.2 Culture Analysis

The Innovation Studios is not a dedicated department space, this space is open to all students to use at any time throughout the day. However as discussed previously the Innovation Studios is a showcase for the school meaning that the space is as much for upper management and advertising for the school as it is for student work. With this being the case there is an unwillingness from management to make changes to the current space, such as moving some of the machines and equipment out of this space to keep the Innovation Studios with it's original design. Without this willingness there seems to be little ways the team could provide solutions to many of the bottlenecking issues their location is facing. This being the case the team decided to explore broader solutions that could begin to ease the space issues and help the location run smoother including analyzing how their safety training compares to the rest of the campus's training.

Chapter 5: Recommendations

Our team was able to discuss recommendations after we analyzed our results. Each campus building in our research was assigned unique recommendations specific to their requirements and customer needs. However, there are limitations to these upcoming recommendations. Our project's research was developed using a snapshot of the operational status of Gordon Library, Higgins Laboratories, and the Innovation Studio during the course of our research. Thus, our findings, insights, and recommendations detailed in this report may not be as applicable if unforeseen alterations in the operational status of the three buildings occur.

5.1 Gordon Library Recommendations

5.1.1 Space Planning Adjustments to Improve Space Optimization

Our first recommendation for the library highlights the management of volume in the library. The open response question in our survey highlighted that volume was the primary attribute contributing to the floor that a student in our sample decided to do work on. We believe that intentionally designing the second floor as a collaboration floor could improve the management of volume in the library.

As indicated in the short response section of our survey, each floor's design prompts a different level of volume. The second floor or entrance floor was described as the loudest, due to the foot traffic of people entering and leaving the building. The first floor was intentionally designed to be a quiet floor, and the third floor accommodates both noisier and quiet volumes due to the mixture of both collaboration and individual based seating

Our second recommendation for the library addresses the issue of space optimization. As shown by our results, we can assess that current patterns of space planning in the library are potentially contributing to under utilization of space in the library. Adding more rectangular and individual tables, while eliminating Dog Bone tables, could improve the utilization of space in the library.

One Dog Bone table takes up the length that four rectangular tables take horizontally placed. However, Dog Bone tables are desired less. Moreover, the current arrangement of the Dog Bone tables are occupying space that a more utilized resource, such as rectangular tables or individual desks, could be occupying. This arrangement is potentially contributing to the under utilization of space within the seating of the library. Additionally, the Dogbone tables are designed for six people, since each cubby in the Dog Bone table has one seat in front of a curved workspace. The design of this resource does not easily allow for collaboration. The curvature in the desks, and the dividers between the different cubbies primarily facilitate individual work. So, it can be concluded that the primary users of Dog Bone tables are potentially working individually. However, using Dog Bone tables in this manner is not optimal.

We can also observe that the usage of Dog Bone Tables on the second floor is potentially contributing to less utilization on the second floor. Our research concluded that of the sample of students who use the library, 13.2% of students prefer to use the second floor. Essentially, the second floor was the least favored and received the least utilization, in comparison to the other floors. We understand that a combination of attributes listed earlier in our research, such as volume, could be contributing to this trend. However, we can conclude that the space planning on the second floor in particular is a prime factor in the under utilization of this floor.

Aside from the Library Cafe, the Technology Desk, offices, and the Library desk, Dog Bone Tables occupy a large percentage of this floor, although our research indicated that Dog Bone tables have the smallest chance of being used at least once during a term. The individual desks, which had the second highest chance of being used at least once during a term aren't present on this floor. Although the rectangular tables, which had the highest chance of being used at least once during a term, are present on this floor, they occupy less space than the Dog Bone tables. Thus, we can conclude that an excess of the under desired Dog Bone tables, and a lack of the more essential resources, such as rectangular tables and individual desks, are making the second floor the least desired and under utilized floor in the library.

5.1.2 Visual Capacity & Availability Displays

Gordon Library's survey trends indicated that students have varied preferences for the floors they are studying on as well as their usage for the specific floors. To aid with efficiency, our team recommends that Gordon Library use visual capacity and availability displays. These availability displays would be posted outside of the library and they would update to indicate the current occupancy of the library as well as the available space. These displays would be most useful if they were broken down by floor, and provided information on the occupancy of resources such as tables or printers. We envision that the software would be able to detect resource usage per floor, by counting the total number of students on a floor and comparing that to the available seats on the floor. Additionally, since each floor has the same entrance and exit point, each student who entered the floor would be counted by a sensor that detects motion in both ways. In essence, these sensors would give the library additional insight on the floor and resource usage and give students awareness on what floors and/or resources are available, so they could avoid wasting time looking for a seat. As the sensors continued to collect data, they could also be used to predict trends such as the busiest times in the library as well as how much time people are spending on different floors.

5.1.3 Create Signs to Describe Intended Resource Usage

Once the space had been designed to optimize efficiency, our team wanted to ensure that the seating space is being increased from the top down, by making sure it is being used for its intended purpose. An example of this concerns the creation of instructional signs that mandate the minimum amount of people required. Kaelyn and Paul's report highlighted a pattern of one student solely occupying a table intended for a group. This behavior automatically reduces the original seating space at this table because students are less likely to sit at a group table with an individual using this table for individual study. Thus, this action can reduce a table that originally seats 8 to just 1, making all efficiency efforts obsolete.

We recommend creating signs that designate the intended use for particular resources. As of this research, there are no signs that explicitly inform students of the correct utilization of a resource. This could be carried out by placing signs at the long rectangular tables indicating that the space is reserved/ intended for students working in a group.

5.2 Higgins Laboratories Recommendations

5.2.1 Create and Maintain an Inventory System

In order to reduce the amount of unnecessary spending on equipment already owned, an inventory management system was created based on the ideas discussed during the faculty interviews to mitigate this issue. This system was created using Excel and the Excel coding language VBA, virtual basic, in order to run smoothly and have it easily understandable to the average user, whether that be a professor or student. The system organizes each item that is added to it based on certain criteria, being type of equipment, availability and necessary safety requirements to use. There is then a keyword search and advanced search button that allows the user to input up to 5 keywords that will then be used to locate any item containing those and present them in a list to the user who will then be able to select items they would like to use. These selections are then sent to a different sheet with a link to a google form for the referral of a lab TA or Professor to approve selection of items. Once complete, the item's availability will change accordingly in the system.

In order to ascertain the effectiveness of the inventory system that was created, we interviewed Professor Radhakrishnan for a second time via zoom to both show and discuss the system. First, the need for the system was discussed with major emphasis on cutting department costs by having a dedicated list of all items present, thus preventing the repeat ordering of certain items[27]. It was also mentioned how the only person currently aware of what items are available is Lab Manager Peter Hefti, who works in the ME department, and how it would be very helpful to him to have an easily accessible and usable inventory system[27]. Next, we discussed how students and faculty would access the system, and we suggested using a QR scan code method in order to send out the file. In order to select which items a user would like to use, the system would include an option to select items and add them to a list which can then be requested using a google form, which would need to be updated and maintained by either the lab manager or a lab T.A. Finally, we discussed how the system would be maintained and we suggested adding it to the responsibilities of Higgins Lab TAs[27]. Updating the sample of this inventory system the team created according to the professors suggestions. We believe our system could be populated with the department's inventory and be used without many other updates to the system; the excel files created are shown in appendix G.

5.2.2 Track Usage of Lab Space

Due to the fact that the team's original understanding of the engineering experimentation lab is very different from how the space will actually be used we were only able to develop broad recommendations that allow for continuous improvement. This includes having a space occupancy system in place for the lab similar to the software that is currently being used at Gordon Library. This could have multiple benefits to the operation of the lab space especially when combined with a reservation system. This would allow students to know the occupancy of the lab before entering and provide an opportunity for students to reserve more collaborative space specifically for ME MQPs which currently there is very limited space. This would also provide WPI with data about how the space is being used this software can be developed to give data on how many students are using the space, how many reservations are made, how many student show up to their reservations, and what machines in the space are being used if through the reservation system they request this information from the students. This space occupancy data combined with student feedback data the team hopes the department will collect can be used to develop a floor plan design that is best fitting the current needs of the students. For example this can be done after data is collected, determine the most accessed machines and make those the most easily accessible ones in the space consistently referring to the data to ensure the design of the space meets the needs of the customers.

5.3 Innovation Studio Recommendations

Following the summation of our results from the Innovation Studio, we were able to develop a few recommendations, including the implementation of building occupancy software, the utilization decision tree for safety training, and the inclusion of an improved student feedback system.

5.3.1 Building Occupancy Software

Based on our interviews with faculty, the Innovation Studio already recognizes and emphasizes the opportunity data collection can provide in managing and improving a facility. Staff at the Innovation Studio already employ the use of data collection software in the form of

Libcal to track reservation statistics. We recommend that the Innovation Studio continue to expand on their data collection practices through the use of a sensor system that can track general occupancy in real time. In particular, we recommend the use of software and hardware from Sensource which has been adopted by Gordon Library. Sensource has a built in compatibility with Libcal meaning staff at the Innovation Studio will not need to retrain on new data software. Due to the many entrances of the Innovation Studio and the price of incorporating Sensource equipment into a facility, we also recommend a limited implementation of sensor equipment to student study areas in the Innovation Studio. In addition, we recommend that the Innovation Studio display current occupancy on the digital screens at the center of the facility so that students may check occupancy at any time. Through a combination of sensor and reservation data, information regarding real time occupancy can be collected which can then be used to make improvements to workspace and study space utilization.

5.3.2 Safety Training Decision Tree

Based upon information provided from interviews with the Innovation Studios, a problem identified was the lack of organization when it comes to students being trained to operate equipment available to them. There are multiple different areas throughout WPI's campus with machine and other hands-on shops that students have access to while for most of the shops only the basic user training is needed there are machines within the Innovation Studios that require additional or other training. One main issue that the Innovation Studio noticed is that within their training there are overlaps with the Basic User Training the school suggests for most other locations. This is causing students to repeat unnecessary training or miss necessary training because they are only completing the basic user training. There are two alternatives the team thought of that the school could do to address this issue: either develop a new basic user training that can be used throughout the whole campus or provide a decision tree that can be shown throughout the school. This type of decision tree would help to provide training information based upon equipment type and location of equipment. This could also help another issue the student population is experiencing of them not being aware of the equipment available for them to use causing them to miss opportunities these resources provide. An example excel file was created, appendix E, with some of the information needed to create this type of decision tree including equipment available, location of equipment, training required and location of training.

5.3.3 Collect Student Feedback on Resource Satisfaction and Utilization

Gordon Library is the only facility in our study that routinely collects feedback on resource satisfaction and utilization. Resource utilization is collected using Sensource, Libcal, and manually counting the number of students using a resource at any given time. Feedback on resource satisfaction is obtained by distributing and analyzing student surveys on resource satisfaction at least once a year. Since Gordon Library collects and stores data on how resources are being used, it's easier to analyze its efficiency and make adjustments where necessary. Observations and studies by Paul Harmon, an author and management consultant, states that utilizing measures, specifically "external" and "internal" are key methods to determine the performance of a system. [17] He also mentions that these external measures could be "measures of customer satisfaction", while internal measures can be "efficiency and effectiveness of specific functions or subprocesses". [17] Therefore, we recommend that the Innovation Studio should start collecting data on resource satisfaction and utilization.

Currently, the only information the Innovation Studio collects on resource usage is by the tech suite reservation data that is monitored by Gordon Library. The Innovation studio could collect data on resource satisfaction and utilization by distributing surveys yearly on how satisfied students are with the current resources in the Innovation Studio. Sample questions for this survey could include:

- How often do you visit the Innovation Studio?
- When you visit the Innovation Studio, how long are you usually there?
- What floor and/or room do you prefer to use while in the Innovation Studio?
- On average, how often do you have to wait for the following resources to be available during a term?
- Of the following improvements to the Innovation Studio, listed below, what do you think are the top three improvements that could make your experience better?
- Do you have any other suggestions or feedback?

Chapter 6: Project Discussion

The purpose of a Major Qualifying Project (MQP) is to tackle real world problems by working with an interdisciplinary team to apply important concepts from one's major. This project granted our team with the opportunity to experience some of the lessons and challenges industrial engineers can encounter when analyzing, improving, and designing a system. During our project we analyzed three different buildings with vastly different cultures, management, functions, and stages of improvement. These conditions prompted our team to adjust our research methods to suit the function, style, and needs of each particular building. In the upcoming sections, we will highlight some of the main realizations we developed during the project.

6.1 Assessing Customer Needs

Similar to the process of analyzing a real world system, the core of our project stemmed from assessing the customer needs. As we have learned in our previous classes, ignoring customer needs can cause a system to be flawed from the start. Therefore, we used Axiomatic Design as the basis for analyzing each facility's system. This allowed us to thoroughly understand the unique customer needs and requirements of a system, while eliminating biases.

6.2 Adjusting to Alterations in Project Scope

During the course of our project, our scope and deliverables changed considerably. Moreover, external factors affecting the specific location of our project directly impacted the deliverables of our project. An example of this concerned a reduction of space in the open space for the new lab in Higgins Laboratories The Mechanical Engineering department was set to receive less of the new planning space than they had originally intended. Thus, changed our idea of redesigning the new lab space using space optimization techniques, to primarily focusing on the inventory management system.

6.3 Communicating Engineering Principles to Non-Engineers

While reporting our progress and intentions to stakeholders, there were multiple times when we had to explain engineering principles, such as Axiomatic Design, to faculty who were not familiar with such concepts. For instance, during our project, we met with the library faculty to present our Axiomatic designs to confirm that our ideologies were accurately representing the library's operating status. During this meeting we were able to briefly explain what Axiomatic design was and how we intended to use it for our project.

6.4 Team Reflection

As a team we found ourselves facing many challenges at the beginning of the project. Our initial proposed MQP was, unfortunately, not feasible due to limitations within our group. As a group we had to hastily find another project and were looking near and far. We eventually decided to create an MQP that could potentially make changes that we would be able to see on campus. This rough takeoff to our MQP was actually very helpful in creating team chemistry and helping us bond. We spent hours together, piecing together project ideas for the Gordon Library and other buildings that we believed would benefit the student population at WPI. Basing the ideas off of the team's own student experience with these locations and previous projects done on campus by some team members. As we progressed into our project, our group was assigned another team member. This caused some problems for our team because the new group member had trouble forming chemistry with each individual within our group. We eventually found some chemistry with this individual and were able to keep our strong team dynamic. Through the many challenges our group had faced, we were able to overcome a very rough beginning and complete in our opinion a successful project. Without these challenges, we would not have been able to learn how to function as a group and develop a project while overcoming internal and external problems. Included in these problems was a constantly changing team dynamics, no individual held the same role throughout the entirety of the project. These changes also allowed the team as individuals to grow and learn where their strengths and weaknesses are when working with others and provided new perspectives on the role an individual can play in having a successful project.

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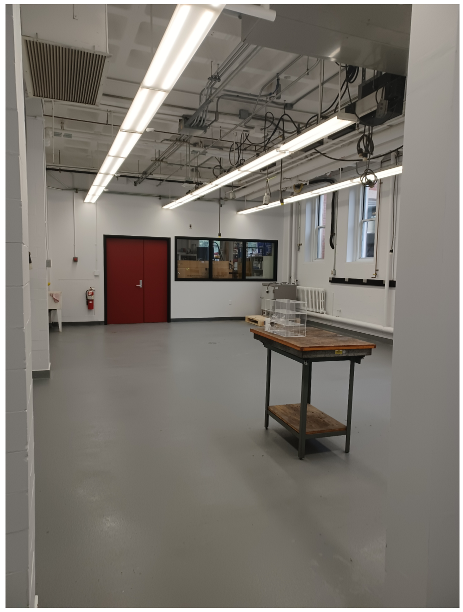
Appendix

Appendix A

Higgins Labs Experimentation Lab - Empty

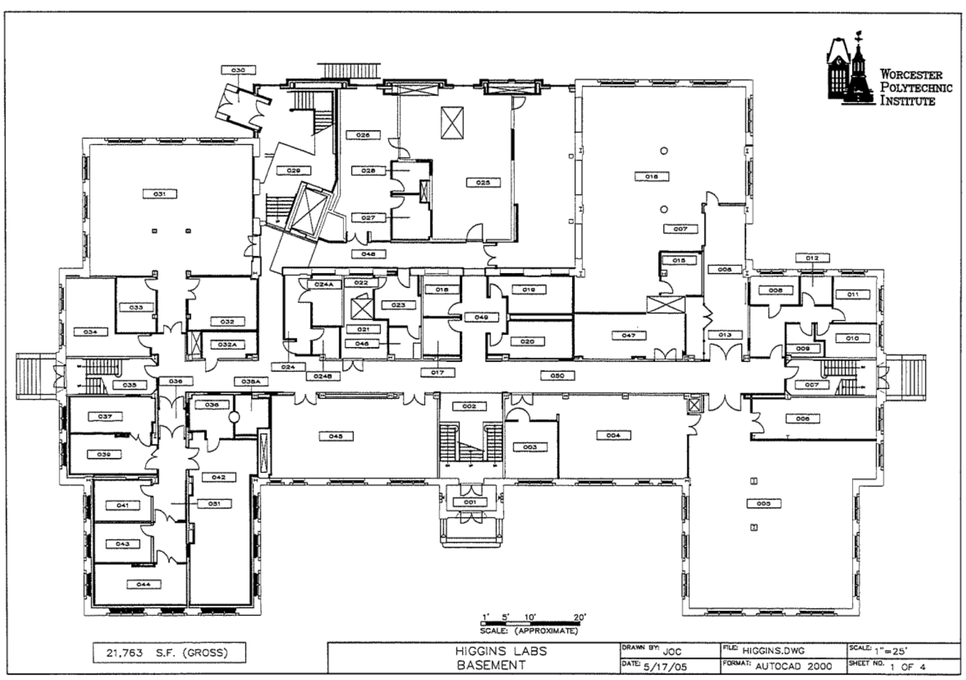


Appendix B

Higgins laboratory's basement floor plans and a simplified version created to visualize the usable space.

Appendix B1

Higgins Labs Basement Floor Plan



Appendix B2

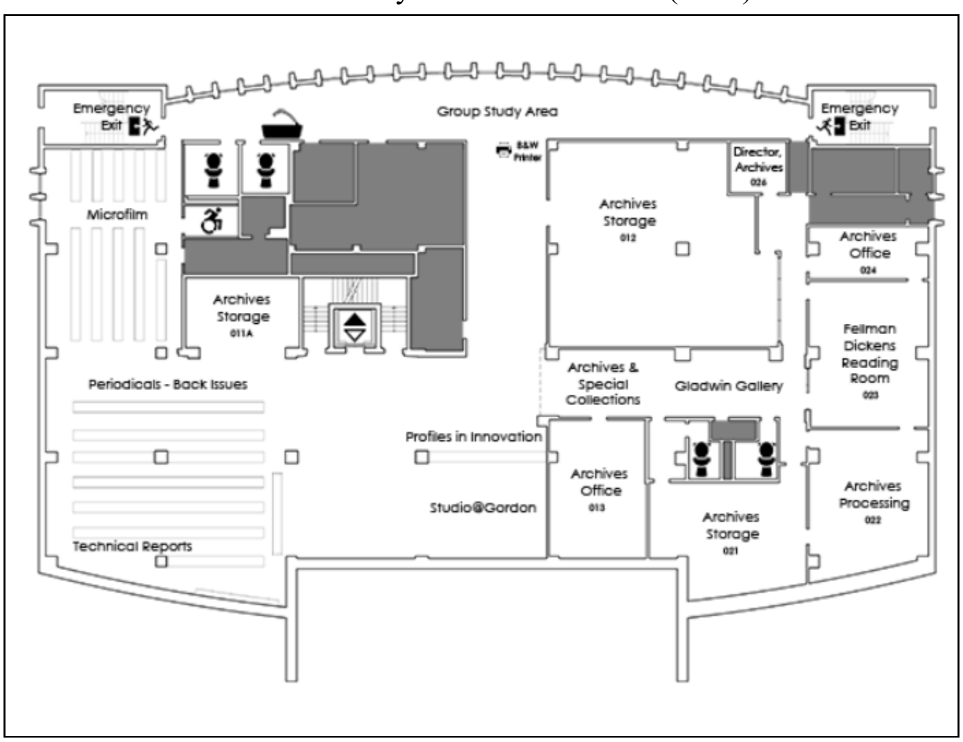
Higgins Labs Basement Floor Plan Handmade Labeled Drawing

Appendix C

Gordon Library's floor plans (2021)

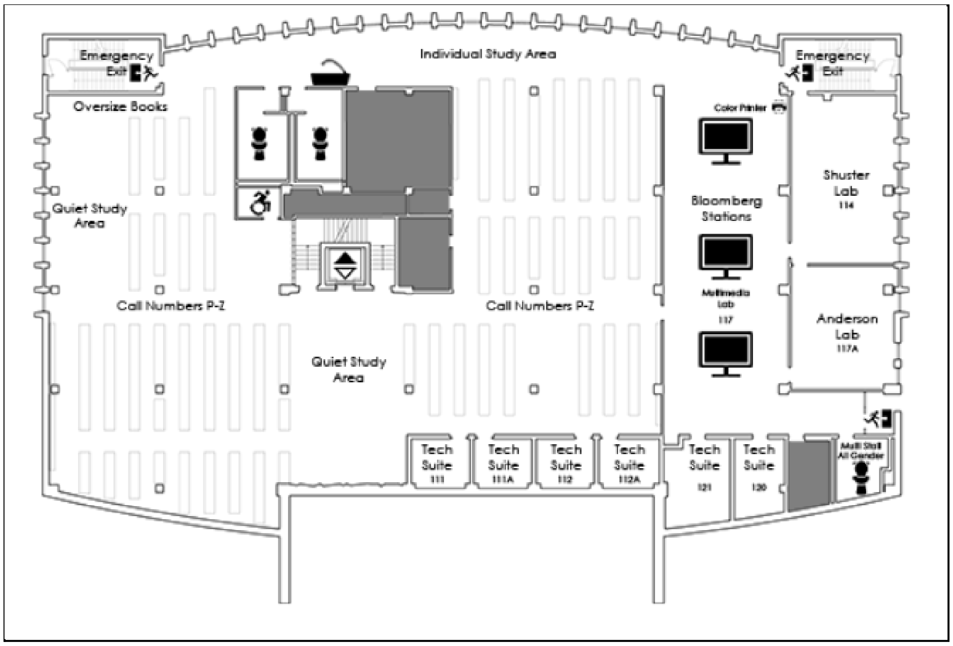
Appendix C1

Gordon Library Ground Floor Plan (2021)



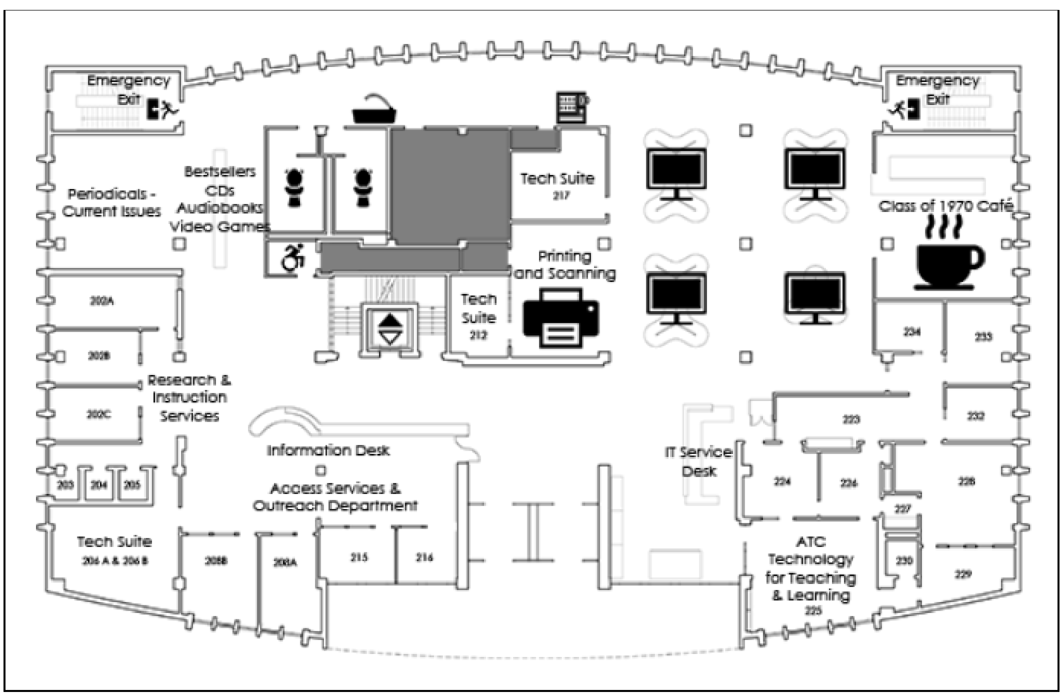
Appendix C2

Gordon Library First Floor Plan (2021)



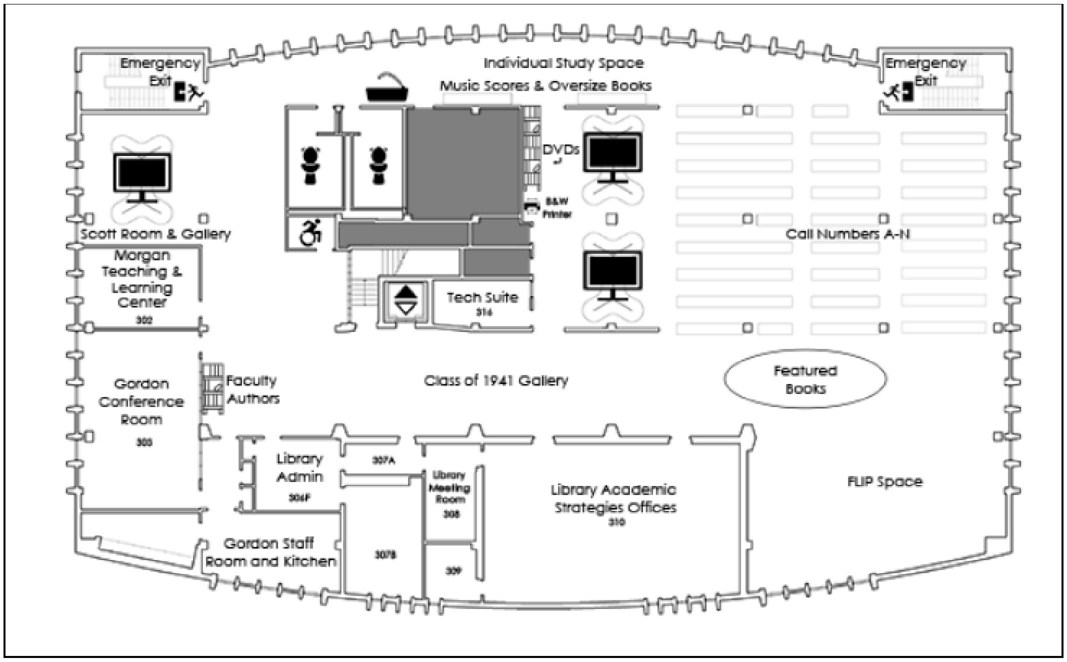
Appendix C3

Gordon Library Second Floor Plan (2021)



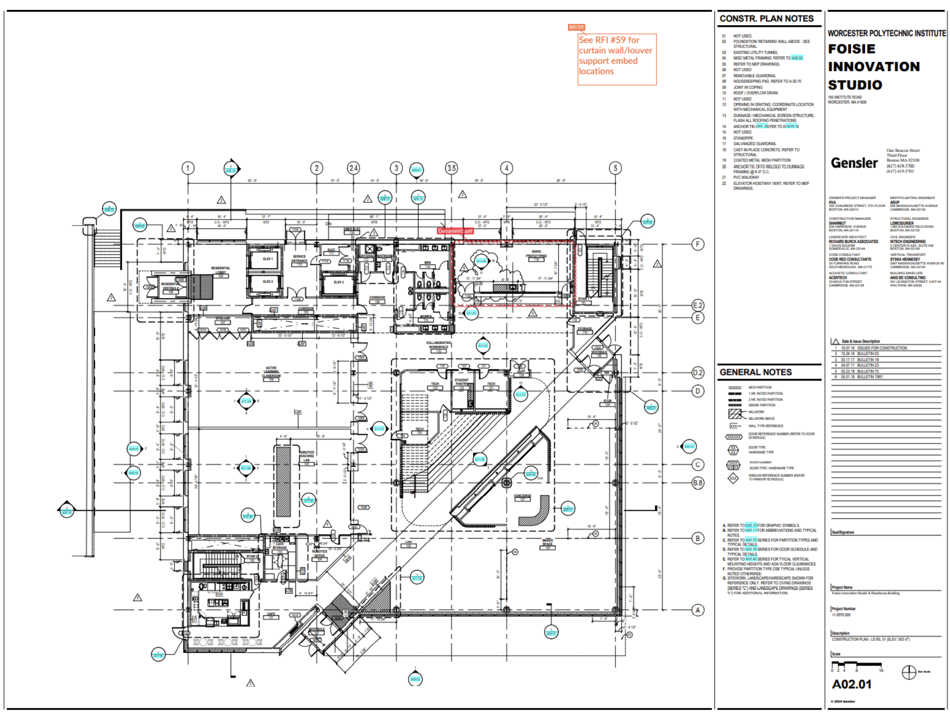
Appendix C4

Gordon Library Third Floor Plan (2021)



Appendix D

Innovation Studio Third Floor Plan



Appendix E

Safety training requirements for on-campus equipment at WPI showing using a Microsoft Excel decision tree.

Safety Certification Decsion Tree

Equipment Available	Location	Training Required	Location Of Training
	Higgins Machine Shop		
Haas Tool Room Min	HL 004	Basic User Training	https://sites.google.com/site/wpimanufacturinglabs/#h.p_CJqUK_g5LrGq
Haas Tool Room Lathe	HL 004	Basic User Training	https://sites.google.com/site/wpimanufacturinglabs/#h.p_CJqUK_g5LrGq
Surface Grinder	HL 005	Basic User Training	https://sites.google.com/site/wpimanufacturinglabs/#h.p_CJqUK_g5LrGq
DoAll Mills	HL 005	Basic User Training	https://sites.google.com/site/wpimanufacturinglabs/#h.p_CJqUK_g5LrGq
DoAll Engine Lathe	HL 005	Basic User Training	https://sites.google.com/site/wpimanufacturinglabs/#h.p_CJqUK_g5LrGq
Drill Press	HL 005	Basic User Training	https://sites.google.com/site/wpimanufacturinglabs/#h.p_CJqUK_g5LrGq
Band Saw	HL 006	Basic User Training	https://sites.google.com/site/wpimanufacturinglabs/#h.p_CJqUK_g5LrGq
	Washburn		
Universal Laser System VLS60 Laser Cutter	Room 107	Basic User Training	https://sites.google.com/site/wpimanufacturinglabs/#h.p_CJqUK_g5LrGq
Makerbot Replicaror 2X	Room 107	Basic User Training	https://sites.google.com/site/wpimanufacturinglabs/#h.p_CJqUK_g5LrGq
Haas Minimills	Room 107	Basic User Training	https://sites.google.com/site/wpimanufacturinglabs/#h.p_CJqUK_g5LrGq
Haas SL10s	Room 107	Basic User Training	https://sites.google.com/site/wpimanufacturinglabs/#h.p_CJqUK_g5LrGq
Band Saws	Room 107	Basic User Training	https://sites.google.com/site/wpimanufacturinglabs/#h.p_CJqUK_g5LrGq
Drill Presses	Room 107	Basic User Training	https://sites.google.com/site/wpimanufacturinglabs/#h.p_CJqUK_g5LrGq
Sheet Metal Shear	Room 107	Basic User Training	https://sites.google.com/site/wpimanufacturinglabs/#h.p_CJqUK_g5LrGq
Sheet Metal Bending Break	Room 107	Basic User Training	https://sites.google.com/site/wpimanufacturinglabs/#h.p_CJqUK_g5LrGq
	Innovation Studios		
LulzBot Taz 6	Makerspace	Additive Manufacturing Basic User Training	https://mfelabs.typeform.com/to/MhFZsTLy
3-D Printers	Makerspace	Additive Manufacturing Basic User Training	https://mfelabs.typeform.com/to/MhFZsTLy
Hand Tools	Makerspace	Basic User Training	https://mfelabs.typeform.com/to/R1uhkMyo
Full Spectrum P-series Laser Cutter	Makerspace	Laser Cutter Training	https://mfelabs.typeform.com/to/h4KJmZNk
Wazer Desktop Waterjet	Makerspace	Laser Cutter Training	https://mfelabs.typeform.com/to/h4KJmZNk
LPKF ProtoLaser S4	Makerspace	Laser Cutter Training	https://mfelabs.typeform.com/to/h4KJmZNk
Industrial Sewing Machine	Makerspace	Industrial Sewing Training	
Ultimaker 3/Ultimaker 3 Extended	Makerspace	Additive Manufacturing Basic User Training	https://mfelabs.typeform.com/to/MhFZsTLy

Appendix F

Data analysis from Libcal software, Gordon Library's space occupancy tracking system.

Appendix F1

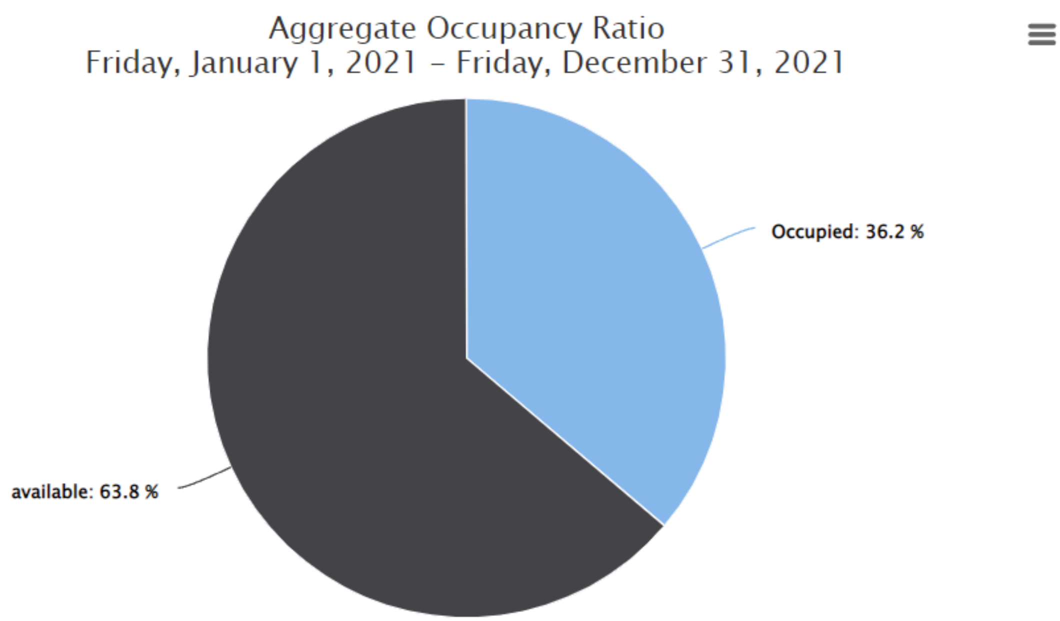
Libcal Gordon Library Tech Suite Reservation Data - Bookings Summary & Aggregate Occupancy

Bookings Summary

Unique Users	Total Bookings	Hours Available	Hours Booked	Average Booking Duration	User Showed Up
1,814	6,815	33,640 hours (3 years, 306 days, 16 hours)	12,174 hours (1 year, 142 days, 5 hours, 50 minutes)	107 minutes (1 hour, 47 minutes)	Yes: 5,848 (98%) No: 126

View Per-Space Bookings Summary

Occupancy Data



Appendix F2

Libcal Gordon Library Tech Suite Reservation Data - Monthly Occupancy

Monthly Occupancy

Statistic Type	January	February	March	April	May	June	July	August	September	October	November	December
Hours Available	-	3,740	3,825	4,030	2,225	1,430	1,300	2,390	4,470	3,665	3,895	2,670
Hours Booked	-	468	1,187	1,477	736	92	32	529	2,370	1,557	2,183	1,545
Occupancy Ratio	-	12.52%	31.02%	36.64%	33.06%	6.40%	2.42%	22.11%	53.02%	42.49%	56.04%	57.87%

Appendix F3

Libcal Gordon Library Tech Suite Reservation Data - Occupancy Distribution by Day & Hour

Day of the Week Occupancy Distribution

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Hours Available	5,660	5,750	5,650	5,420	4,975	2,615	3,570
Hours Booked	2,225	2,243	2,349	2,221	1,580	468	1,089
Occupancy Ratio	39.31%	39.00%	41.57%	40.98%	31.76%	17.89%	30.51%

Hourly Occupancy Distribution

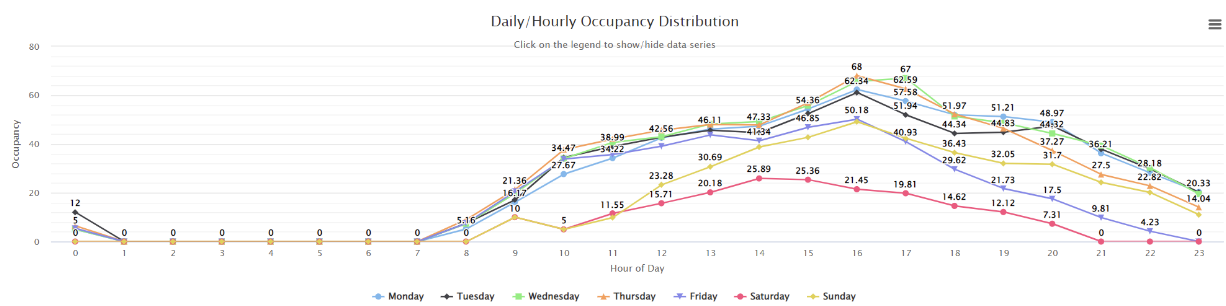
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Hours Available	350	-	-	-	-	-	-	-	1,570	2,270	2,290	2,815	2,810	2,810	2,810	2,485	2,100	2,020	2,005	1,970	1,810	1,650	1,175	700
Hours Booked	24	-	-	-	-	-	-	-	115	429	757	922	1,067	1,184	1,218	1,216	1,147	1,003	818	737	652	488	281	120
Occupancy Ratio	6.86%	-	-	-	-	-	-	-	7.29%	18.89%	33.03%	32.74%	37.96%	42.13%	43.33%	48.94%	54.62%	49.63%	40.79%	37.40%	36.05%	29.55%	23.89%	17.10%

Appendix F4

Libcal Gordon Library Tech Suite Reservation Data - Daily/Hourly Occupancy Distribution

Daily/Hourly Occupancy Distribution

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Monday	5.00%	-	-	-	-	-	-	-	5.16%	16.17%	27.67%	34.22%	42.56%	46.11%	47.33%	54.36%	62.34%	57.58%	51.97%	51.21%	48.97%	36.21%	28.18%	20.33%
Tuesday	12.00%	-	-	-	-	-	-	-	7.50%	17.13%	34.47%	38.99%	42.77%	45.64%	44.63%	52.50%	61.09%	51.94%	44.34%	44.83%	47.37%	37.86%	29.76%	20.18%
Wednesday	5.00%	-	-	-	-	-	-	-	7.34%	19.78%	34.02%	40.66%	43.00%	48.22%	49.22%	55.78%	65.65%	67.00%	51.33%	48.67%	44.32%	39.31%	30.23%	19.46%
Thursday	6.43%	-	-	-	-	-	-	-	9.03%	21.36%	37.73%	42.05%	45.68%	48.01%	47.84%	56.93%	68.00%	62.59%	52.24%	46.38%	37.27%	27.50%	22.82%	14.04%
Friday	5.38%	-	-	-	-	-	-	-	7.50%	20.58%	33.84%	35.70%	39.11%	43.72%	41.34%	46.85%	50.18%	40.93%	29.62%	21.73%	17.50%	9.81%	4.23%	-
Saturday	-	-	-	-	-	-	-	-	-	10.00%	5.00%	11.55%	15.71%	20.18%	25.89%	25.36%	21.45%	19.81%	14.62%	12.12%	7.31%	-	-	-
Sunday	-	-	-	-	-	-	-	-	-	10.00%	5.00%	9.83%	23.28%	30.69%	38.79%	42.76%	49.14%	42.32%	36.43%	32.05%	31.70%	24.26%	20.12%	11.01%



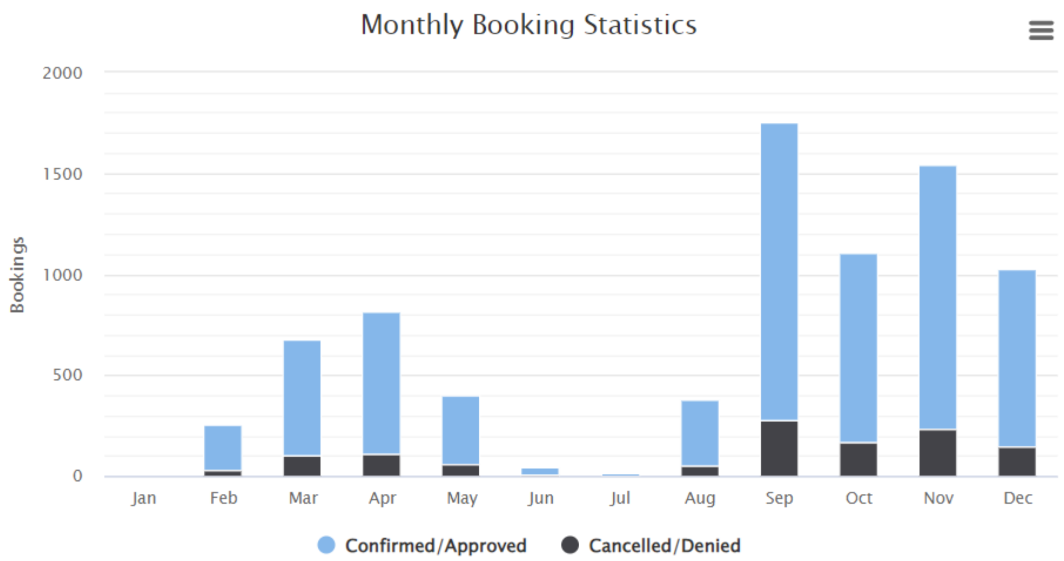
Appendix F5

Libcal Gordon Library Tech Suite Reservation Data - Bookings by Month

Bookings by Month

	January	February	March	April	May	June	July	August	September	October	November	December
Booking Submissions	-	256	674	818	397	43	13	377	1,754	1,103	1,539	1,025
Confirmed/Approved	-	225	574	708	336	39	13	325	1,474	936	1,305	880
Cancelled/Denied	-	31	100	110	61	4	-	52	280	167	234	145

View detailed monthly breakdown by booking status.



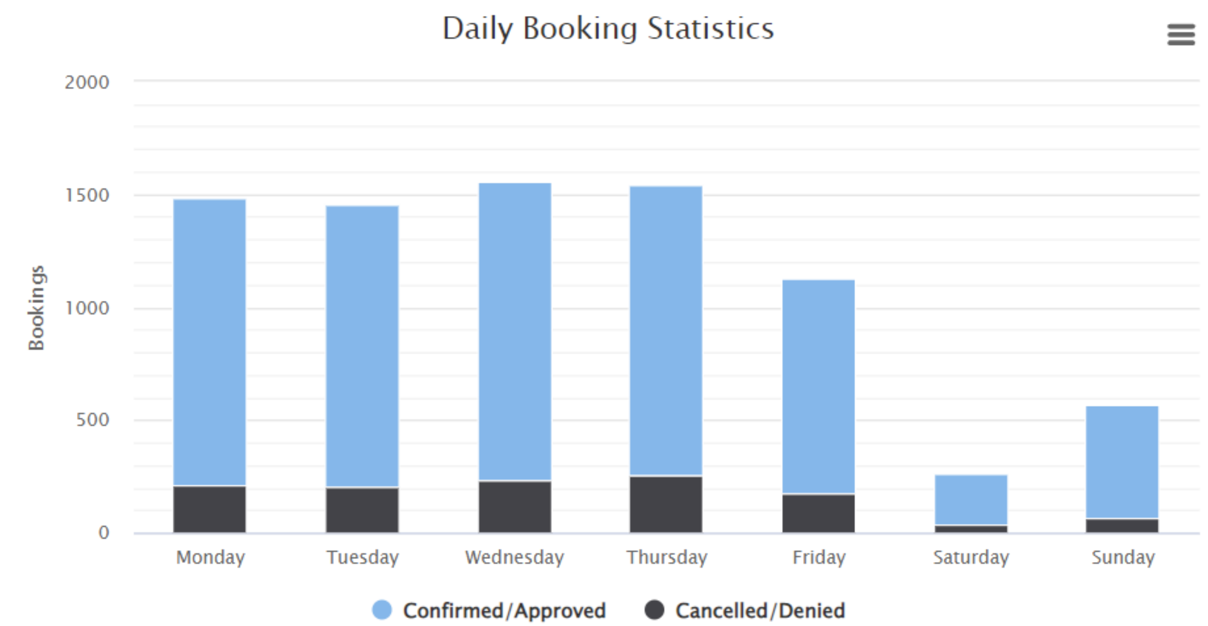
Appendix F6

Libcal Gordon Library Tech Suite Reservation Data - Bookings by Day of the Week

Bookings by Day of the Week

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Booking Submissions	1,483	1,454	1,556	1,545	1,130	261	570
Confirmed/Approved	1,275	1,251	1,321	1,289	953	225	501
Cancelled/Denied	208	203	235	256	177	36	69

View detailed daily breakdown by booking status.



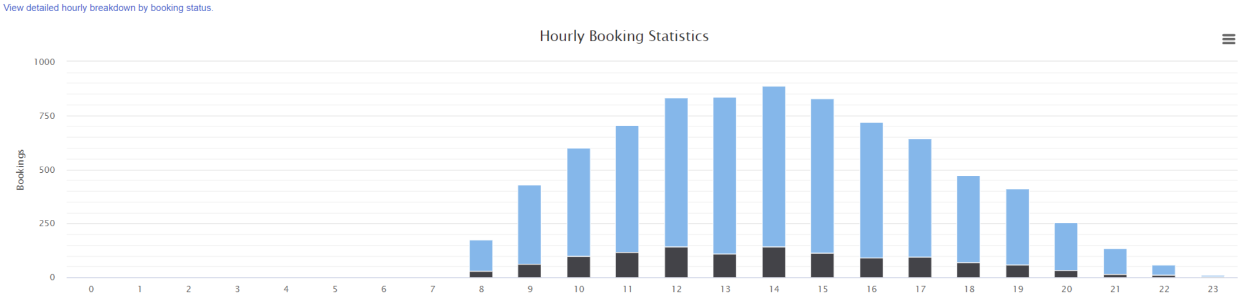
Appendix F7

Libcal Gordon Library Tech Suite Reservation Data - Bookings by Hour of the Day

Bookings by Hour of the Day

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Booking Submissions	1	-	-	-	-	-	-	-	176	430	599	704	833	837	889	829	720	645	471	410	254	134	57	10
Confirmed/Approved	1	-	-	-	-	-	-	-	146	369	501	588	690	729	747	715	630	550	401	350	223	120	47	8
Cancelled/Denied	-	-	-	-	-	-	-	-	30	61	98	116	143	108	142	114	90	95	70	60	31	14	10	2

View detailed hourly breakdown by booking status.



Appendix F8

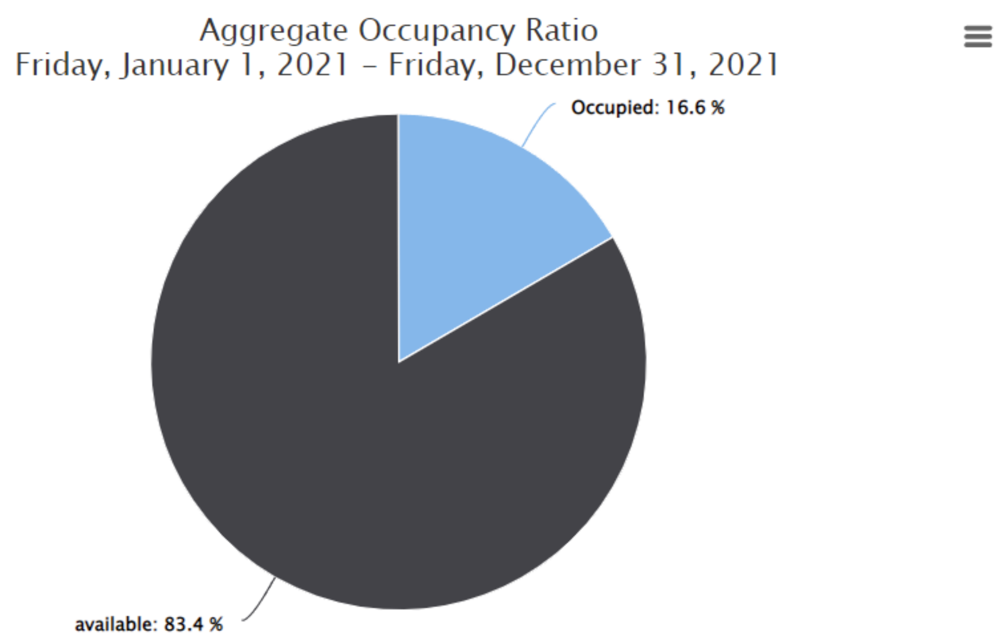
Libcal Innovation Studio Reservation Data - Bookings Summary & Aggregate Occupancy

Bookings Summary

Unique Users	Total Bookings	Hours Available	Hours Booked	Average Booking Duration	User Showed Up
1,736	9,969	100,493 hours (11 years, 172 days, 5 hours)	16,682 hours (1 year, 330 days, 2 hours, 13 minutes)	100 minutes (1 hour, 40 minutes)	Yes: 547 (91%) No: 55

View Per-Category Bookings Summary

Occupancy Data



Appendix F9

Libcal Innovation Studio Reservation Data - Monthly Occupancy

Monthly Occupancy

Statistic Type	January	February	March	April	May	June	July	August	September	October	November	December
Hours Available	5,668	2,535	3,770	12,610	13,000	7,124	-	5,368	14,840	13,472	13,074	9,032
Hours Booked	16	397	1,838	1,895	1,439	54	38	315	2,492	2,799	2,993	2,407
Occupancy Ratio	0.28%	15.65%	48.74%	15.03%	11.07%	0.75%	-	5.87%	16.79%	20.78%	22.89%	26.65%

Appendix F10

Libcal Innovation Studio Reservation Data - Occupancy Distribution by Day & Hour

Day of the Week Occupancy Distribution

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Hours Available	14,561	14,977	14,907	14,791	15,077	13,446	12,734
Hours Booked	3,066	2,990	2,989	2,610	2,190	1,260	1,579
Occupancy Ratio	21.05%	19.96%	20.05%	17.64%	14.52%	9.37%	12.40%

Hourly Occupancy Distribution

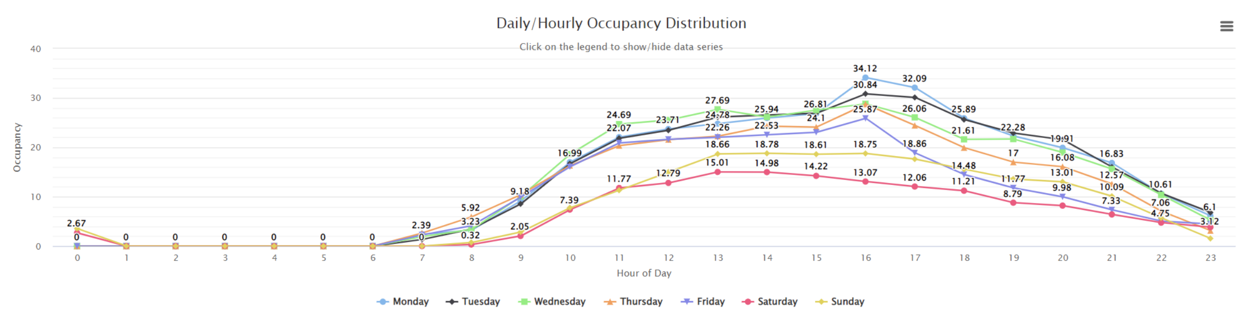
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Hours Available	777	-	-	-	-	-	-	1,898	5,668	6,162	6,504	6,804	6,804	6,804	6,804	6,804	6,280	6,250	6,250	6,065	5,880	5,802	5,511	3,426
Hours Booked	32	8	8	8	8	8	8	41	174	481	948	1,316	1,418	1,541	1,567	1,589	1,627	1,449	1,207	1,033	917	713	431	152
Occupancy Ratio	4.05%	-	-	-	-	-	-	2.16%	3.06%	7.81%	14.58%	19.33%	20.83%	22.64%	23.03%	23.35%	25.91%	23.19%	19.31%	17.03%	15.59%	12.29%	7.83%	4.44%

Appendix F11

Libcal Innovation Studio Reservation Data - Daily/Hourly Occupancy Distribution

Daily/Hourly Occupancy Distribution

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Monday	-	-	-	-	-	-	-	2.39%	3.23%	9.18%	16.99%	22.07%	23.71%	24.78%	25.94%	26.81%	34.12%	32.09%	25.89%	22.28%	19.91%	16.83%	10.61%	6.10%
Tuesday	-	-	-	-	-	-	-	1.35%	3.46%	8.55%	16.69%	21.83%	23.45%	26.14%	26.55%	26.91%	30.84%	30.10%	25.62%	22.88%	21.54%	16.00%	10.67%	6.79%
Wednesday	-	-	-	-	-	-	-	1.92%	3.37%	10.04%	18.62%	24.69%	25.53%	27.69%	26.14%	27.54%	28.81%	26.06%	21.61%	21.67%	18.95%	15.60%	10.37%	5.26%
Thursday	-	-	-	-	-	-	-	2.65%	5.92%	10.42%	16.31%	20.35%	21.56%	22.26%	24.30%	24.10%	28.73%	24.42%	19.92%	17.00%	16.08%	12.57%	7.06%	3.12%
Friday	-	-	-	-	-	-	-	2.27%	4.13%	9.93%	16.07%	20.89%	21.61%	22.04%	22.53%	23.04%	25.87%	18.86%	14.48%	11.77%	9.98%	7.33%	5.06%	4.49%
Saturday	2.67%	-	-	-	-	-	-	-	0.32%	2.05%	7.39%	11.77%	12.79%	15.01%	14.98%	14.22%	13.07%	12.06%	11.21%	8.79%	8.20%	6.41%	4.75%	3.84%
Sunday	3.54%	-	-	-	-	-	-	-	0.74%	2.85%	7.76%	11.31%	14.99%	18.66%	18.78%	18.61%	18.75%	17.62%	15.57%	13.58%	13.01%	10.09%	5.71%	1.55%



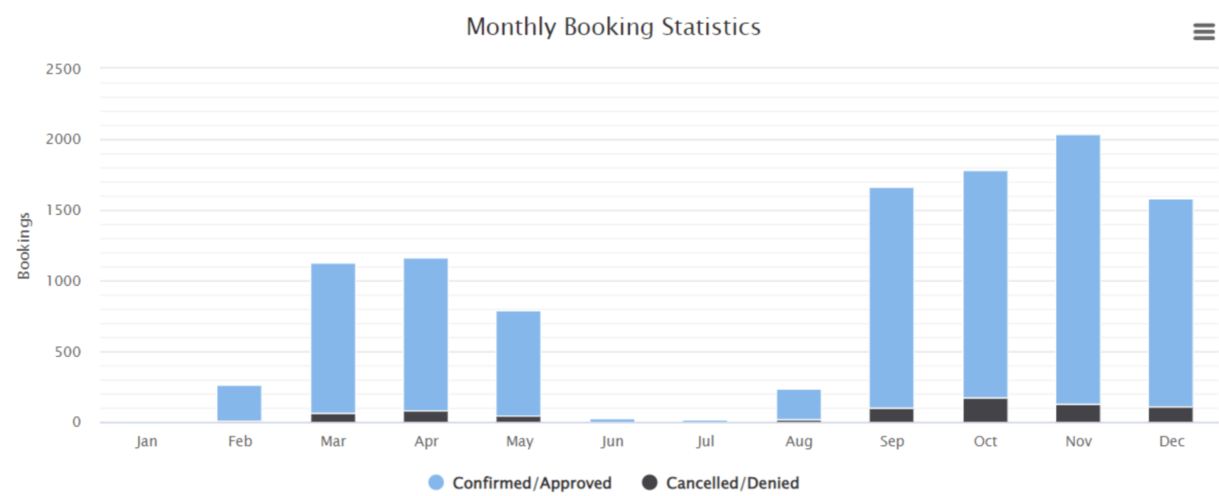
Appendix F12

Libcal Innovation Studio Reservation Data - Bookings by Month

Bookings by Month

	January	February	March	April	May	June	July	August	September	October	November	December
Booking Submissions	9	268	1,131	1,167	788	26	21	234	1,661	1,783	2,039	1,578
Confirmed/Approved	8	258	1,067	1,082	742	26	20	214	1,559	1,614	1,910	1,469
Cancelled/Denied	1	10	64	85	46	-	1	20	102	169	129	109

View detailed monthly breakdown by booking status.



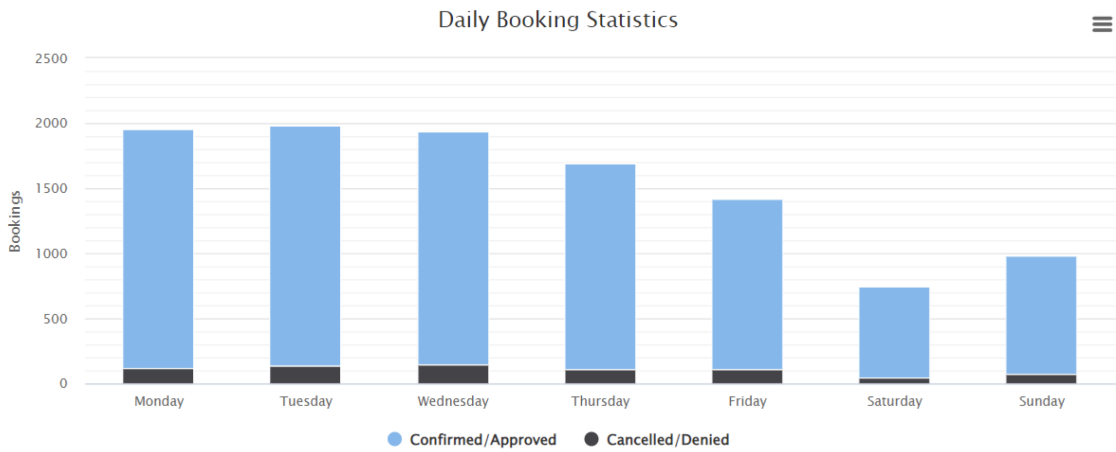
Appendix F13

Libcal Innovation Studio Reservation Data - Bookings by Day of the Week

Bookings by Day of the Week

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Booking Submissions	1,952	1,980	1,936	1,689	1,421	746	981
Confirmed/Approved	1,833	1,844	1,795	1,577	1,309	701	910
Cancelled/Denied	119	136	141	112	112	45	71

View detailed daily breakdown by booking status.



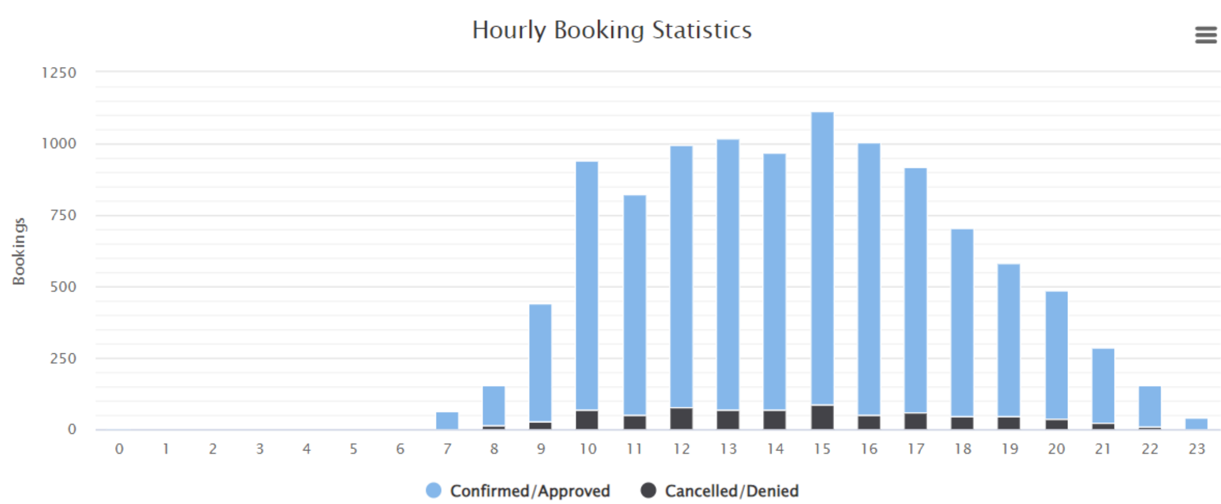
Appendix F14

Libcal Innovation Studio Reservation Data - Bookings by Hour of the Day

Bookings by Hour of the Day

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Booking Submissions	6	-	-	-	-	-	-	64	156	439	939	824	996	1,019	969	1,115	1,004	918	705	584	486	287	154	40
Confirmed/Approved	6	-	-	-	-	-	-	62	144	411	869	772	919	950	901	1,029	953	859	658	540	448	266	144	38
Cancelled/Denied	-	-	-	-	-	-	-	2	12	28	70	52	77	69	68	86	51	59	47	44	38	21	10	2

View detailed hourly breakdown by booking status.



Appendix F15

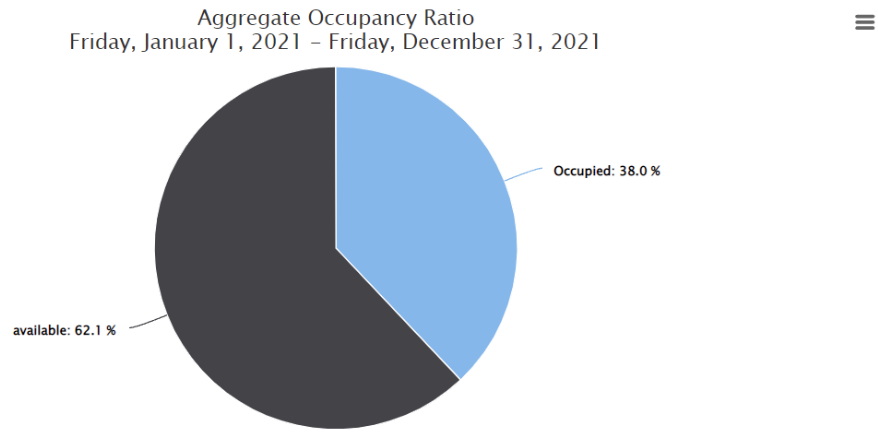
Libcal Innovation Studio Tech Suite Reservation Data - Bookings Summary & Aggregate Occupancy

Bookings Summary

Unique Users	Total Bookings	Hours Available	Hours Booked	Average Booking Duration
1,215	4,919	21,426 hours (2 years, 162 days, 18 hours)	8,132 hours (338 days, 19 hours, 59 minutes)	99 minutes (1 hour, 39 minutes)

View Per-Space Bookings Summary

Occupancy Data



Monthly Occupancy

Statistic Type	January	February	March	April	May	June	July	August	September	October	November	December
Hours Available	1,308	585	870	2,910	3,000	1,644	-	1,164	2,904	2,697	2,556	1,788
Hours Booked	4	166	856	1,055	531	32	25	255	1,505	1,263	1,422	1,020
Occupancy Ratio	0.31%	28.33%	98.36%	36.26%	17.71%	1.95%	-	21.86%	51.83%	46.81%	55.61%	57.03%

Appendix F16

Libcal Innovation Studio Tech Suite Reservation Data - Monthly Occupancy

Monthly Occupancy

Statistic Type	January	February	March	April	May	June	July	August	September	October	November	December
Hours Available	1,308	585	870	2,910	3,000	1,644	-	1,164	2,904	2,697	2,556	1,788
Hours Booked	4	166	856	1,055	531	32	25	255	1,505	1,263	1,422	1,020
Occupancy Ratio	0.31%	28.33%	98.36%	36.26%	17.71%	1.95%	-	21.86%	51.83%	46.81%	55.61%	57.03%

Appendix F17

Libcal Innovation Studio Tech Suite Reservation Data - Occupancy Distribution by Day & Hour

Day of the Week Occupancy Distribution

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Hours Available	3,102	3,198	3,186	3,171	3,201	2,862	2,706
Hours Booked	1,552	1,424	1,391	1,396	991	532	845
Occupancy Ratio	50.04%	44.51%	43.67%	44.03%	30.97%	18.60%	31.23%

Hourly Occupancy Distribution

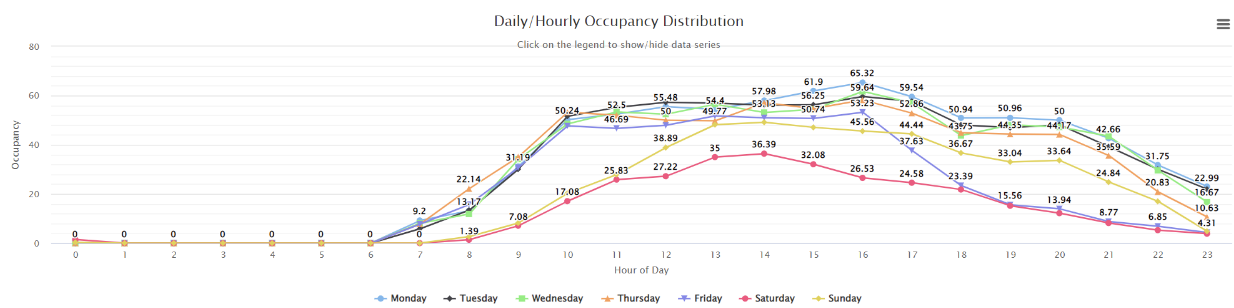
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Hours Available	162	-	-	-	-	-	-	438	1,308	1,422	1,422	1,422	1,422	1,422	1,422	1,422	1,308	1,308	1,308	1,266	1,224	1,206	1,188	756
Hours Booked	7	5	5	5	5	5	5	34	152	370	601	649	678	722	739	733	695	627	506	465	443	356	245	81
Occupancy Ratio	4.01%	-	-	-	-	-	-	7.71%	11.62%	26.04%	42.28%	45.64%	47.70%	50.77%	51.97%	51.56%	53.13%	47.92%	38.69%	36.69%	36.15%	29.52%	20.62%	10.71%

Appendix F18

Libcal Innovation Studio Tech Suite Reservation Data - Daily/Hourly Occupancy Distribution

Daily/Hourly Occupancy Distribution

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Monday	-	-	-	-	-	-	-	9.20%	13.17%	31.19%	50.24%	52.50%	55.48%	54.40%	57.98%	61.90%	65.32%	59.54%	50.94%	50.96%	50.00%	42.66%	31.75%	22.99%
Tuesday	-	-	-	-	-	-	-	5.83%	13.41%	30.09%	51.62%	55.21%	57.29%	56.94%	56.13%	56.25%	59.64%	57.68%	48.05%	46.96%	48.12%	39.21%	30.00%	21.94%
Wednesday	-	-	-	-	-	-	-	8.06%	11.85%	34.14%	48.50%	53.36%	52.43%	56.48%	53.13%	54.40%	61.72%	57.03%	43.75%	48.12%	47.22%	43.47%	29.58%	16.67%
Thursday	-	-	-	-	-	-	-	7.76%	22.14%	35.07%	53.24%	51.97%	50.00%	49.77%	57.06%	54.75%	58.20%	52.86%	44.92%	44.35%	44.17%	35.59%	20.83%	10.63%
Friday	-	-	-	-	-	-	-	7.74%	15.73%	30.76%	47.67%	46.69%	47.92%	51.72%	50.98%	50.74%	53.23%	37.63%	23.39%	15.56%	13.94%	8.77%	6.85%	4.31%
Saturday	1.49%	-	-	-	-	-	-	-	1.39%	7.08%	17.08%	25.83%	27.22%	35.00%	36.39%	32.08%	26.53%	24.58%	21.81%	15.20%	12.19%	8.18%	5.29%	3.85%
Sunday	0.32%	-	-	-	-	-	-	-	2.64%	8.19%	20.28%	27.92%	38.89%	48.19%	49.17%	47.08%	45.56%	44.44%	36.67%	33.04%	33.64%	24.84%	16.99%	4.81%



Appendix F19

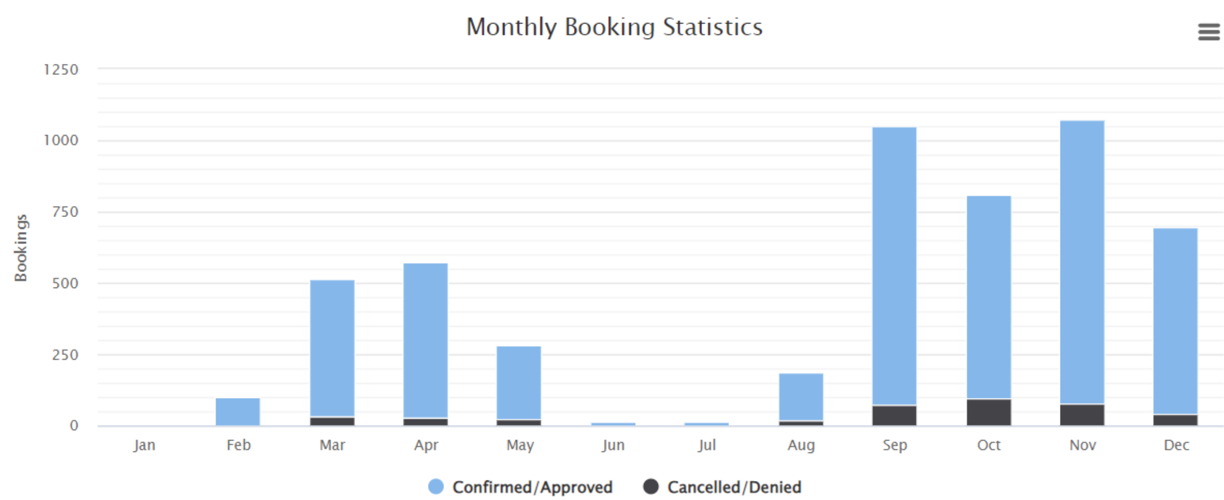
Libcal Innovation Studio Tech Suite Reservation Data - Bookings by Month

Bookings Data

Bookings by Month

	January	February	March	April	May	June	July	August	September	October	November	December
Booking Submissions	2	99	512	573	282	15	12	187	1,048	810	1,073	696
Confirmed/Approved	2	97	481	544	261	15	12	168	973	714	995	657
Cancelled/Denied	-	2	31	29	21	-	-	19	75	96	78	39

View detailed monthly breakdown by booking status.



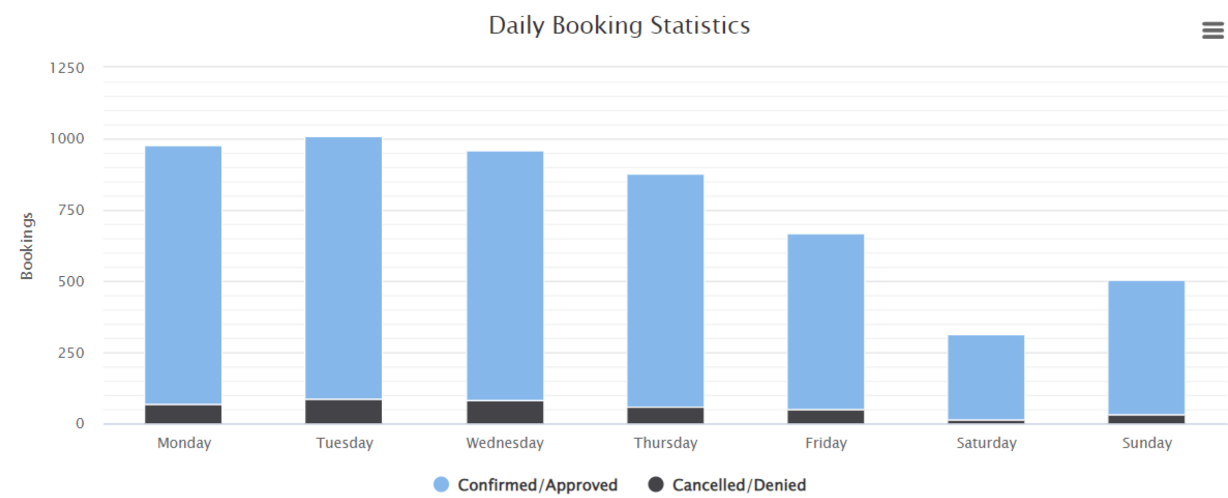
Appendix F20

Libcal Innovation Studio Tech Suite Reservation Data - Bookings by Day of the Week

Bookings by Day of the Week

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Booking Submissions	978	1,008	958	877	667	315	506
Confirmed/Approved	910	920	874	820	618	301	476
Cancelled/Denied	68	88	84	57	49	14	30

View detailed daily breakdown by booking status.



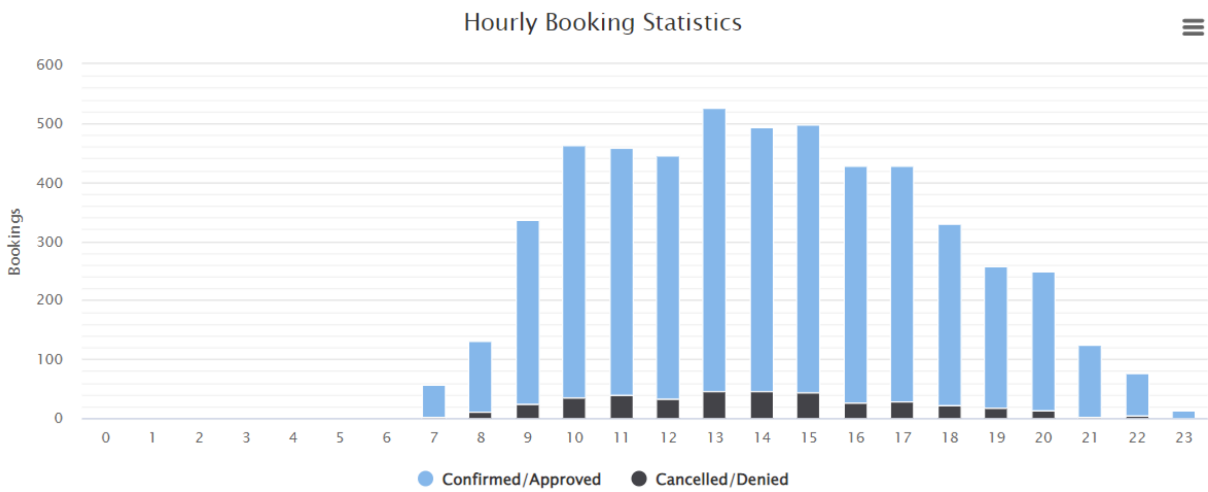
Appendix F21

Libcal Innovation Studio Tech Suite Reservation Data - Bookings by Hour of the Day

Bookings by Hour of the Day

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Booking Submissions	-	-	-	-	-	-	-	57	132	335	462	458	445	526	493	497	427	428	330	257	248	124	76	14
Confirmed/Approved	-	-	-	-	-	-	-	55	121	311	426	419	412	481	448	454	401	400	309	240	234	122	72	14
Cancelled/Denied	-	-	-	-	-	-	-	2	11	24	36	39	33	45	45	43	26	28	21	17	14	2	4	-

View detailed hourly breakdown by booking status.

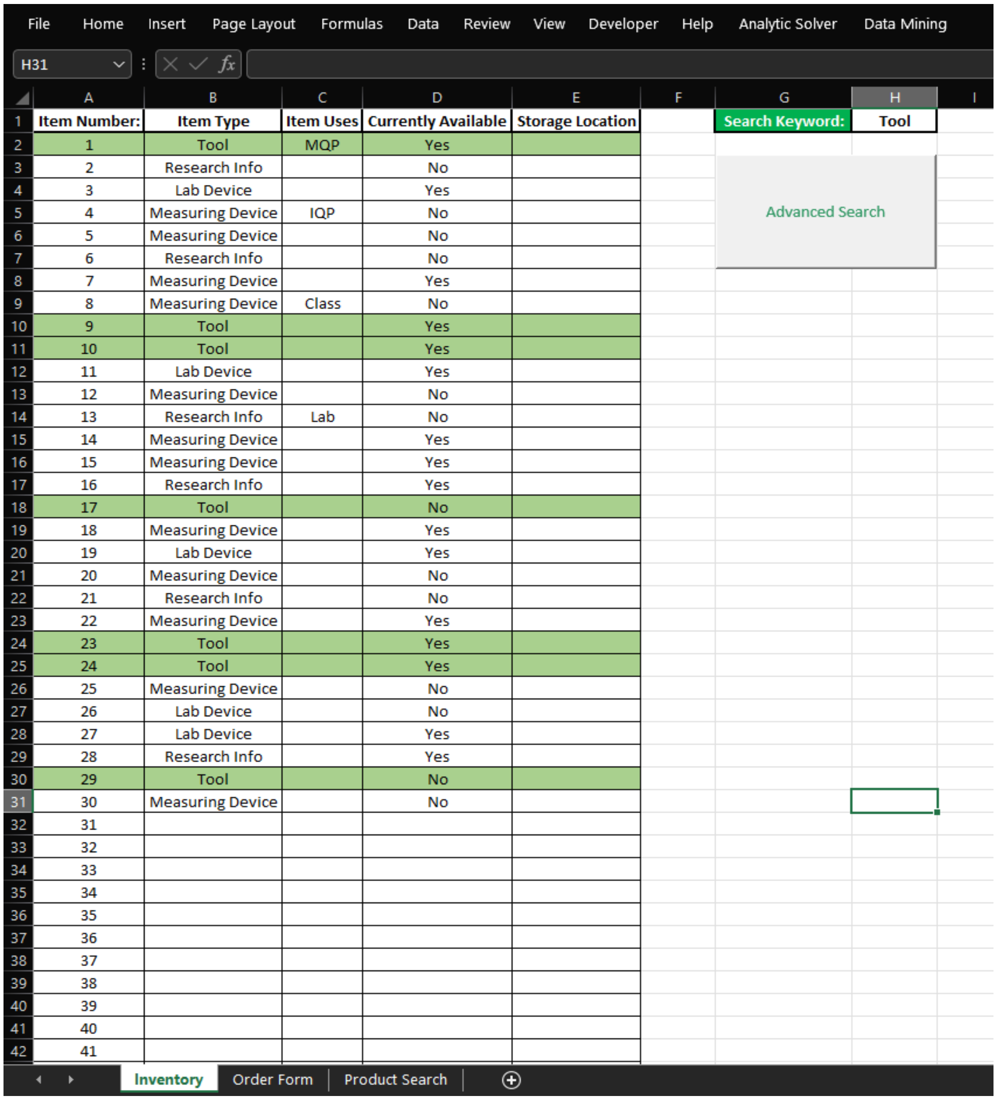


Appendix G

Microsoft Excel Inventory Management System

Appendix G1

Inventory System Search Tools - Keyword and Advanced



Item Number:	Item Type	Item Uses	Currently Available	Storage Location
1	Tool	MQP	Yes	
2	Research Info		No	
3	Lab Device		Yes	
4	Measuring Device	IQP	No	
5	Measuring Device		No	
6	Research Info		No	
7	Measuring Device		Yes	
8	Measuring Device	Class	No	
9	Tool		Yes	
10	Tool		Yes	
11	Lab Device		Yes	
12	Measuring Device		No	
13	Research Info	Lab	No	
14	Measuring Device		Yes	
15	Measuring Device		Yes	
16	Research Info		Yes	
17	Tool		No	
18	Measuring Device		Yes	
19	Lab Device		Yes	
20	Measuring Device		No	
21	Research Info		No	
22	Measuring Device		Yes	
23	Tool		Yes	
24	Tool		Yes	
25	Measuring Device		No	
26	Lab Device		No	
27	Lab Device		Yes	
28	Research Info		Yes	
29	Tool		No	
30	Measuring Device		No	
31				
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38				
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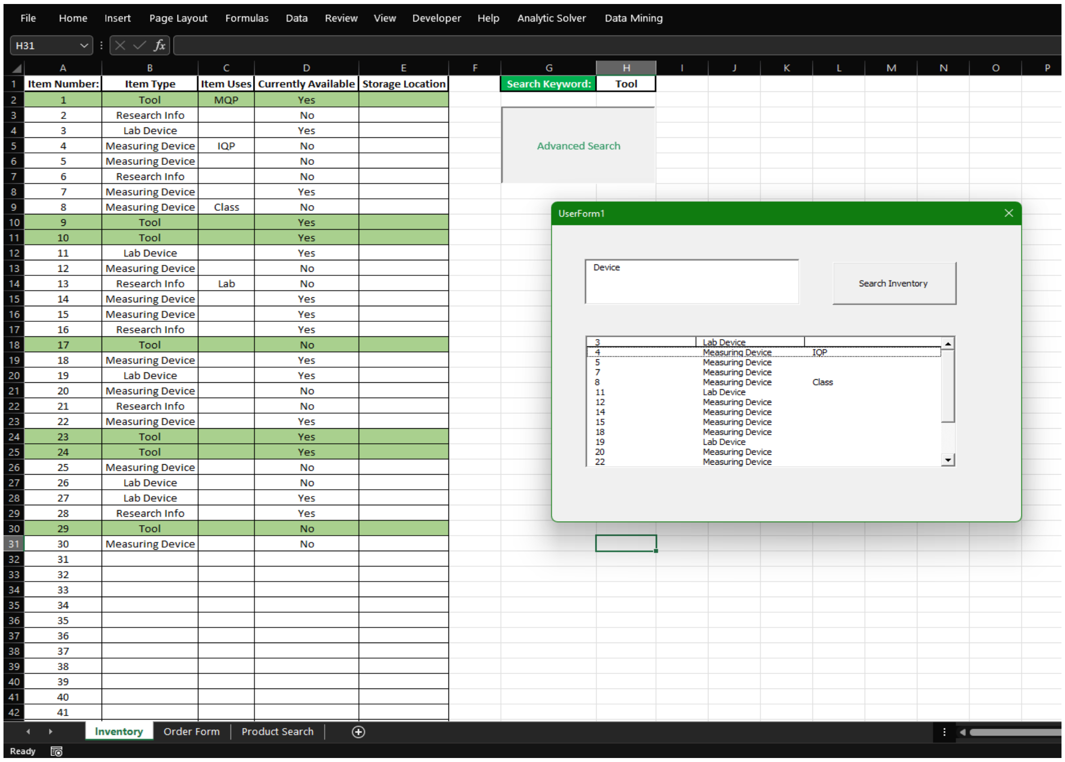
41				

Appendix G2

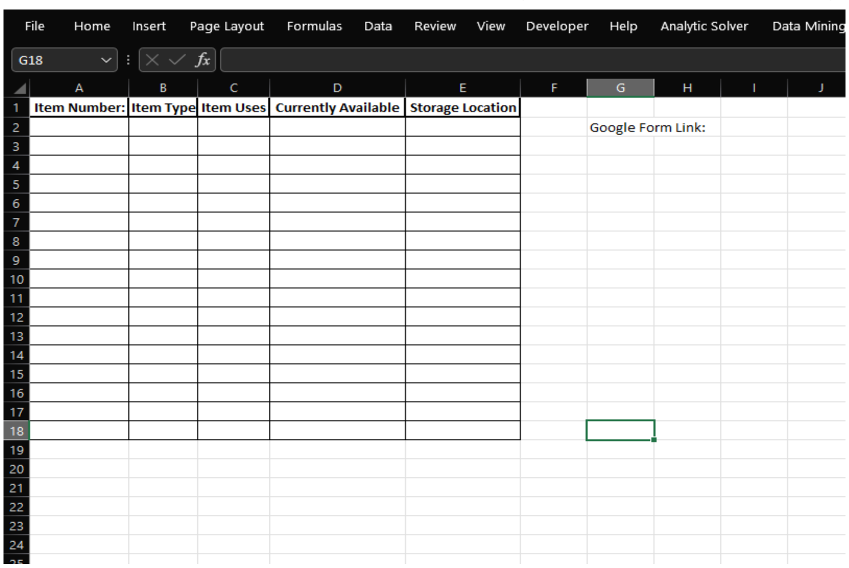
Inventory System Advanced Search Tool Results



Item Number:	Item Type	Item Uses	Currently Available	Storage Location
1	Tool	MQP	Yes	
2	Research Info		No	
3	Lab Device		Yes	
4	Measuring Device	IQP	No	
5	Measuring Device		No	
6	Research Info		No	
7	Measuring Device		Yes	
8	Measuring Device	Class	No	
9	Tool		Yes	
10	Tool		Yes	
11	Lab Device		Yes	
12	Measuring Device		No	
13	Research Info	Lab	No	
14	Measuring Device		Yes	
15	Measuring Device		Yes	
16	Research Info		Yes	
17	Tool		No	
18	Measuring Device		Yes	
19	Lab Device		Yes	
20	Measuring Device		No	
21	Research Info		No	
22	Measuring Device		Yes	
23	Tool		Yes	
24	Tool		Yes	
25	Measuring Device		No	
26	Lab Device		No	
27	Lab Device		Yes	
28	Research Info		Yes	
29	Tool		No	
30	Measuring Device		No	
31				
32				
33				
34				
35				
36				
37				
38				
39				
40				
41				

Appendix G3

Inventory System Advanced Search - Selected Items Page (to be submitted using Google Forms)



Item Number:	Item Type	Item Uses	Currently Available	Storage Location