Chemical and Inventory Management System
SoFab Inks
Team 3

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1 Introduction/Executive Summary

1.1 Introducing SoFab Inks

SoFab Inks is a chemical manufacturing startup that was spun-out from the University of Louisville, Conn Center for Renewable Energy Research with support from the US DoE. SoFab inks focuses on accelerating the commercialization of Perovskite Solar Cells through the development and manufacturing of functionalized inks that improve cell efficiency, reduce module cost, and enable scalable manufacturing. [1]

1.2 SoFab Inks Inventory Management Problem

SoFab Inks is doing important work in the field of solar cell technology, helping to drive humanity towards a cleaner, more energy abundant future. The problem, however, is that the team currently faces issues with managing inventory. These challenges prevent SoFab's talented team from working on the most important aspects of their work. These challenges include expending valuable energy on menial tasks like locating inventory, managing a growing number of shipments manually, scouring inventory entries found across several Google Sheets or handwritten labels to pinpoint important product information, and more.

To aid SoFab in these challenges, this semester Team 3 was tasked with developing a more efficient method of managing inventory items. To accomplish this, the team employed various existing software solutions, including database software, CRUD[1] user interface software, and solutions to containerize this software together into one package. The team also developed custom software to provide features not available in the existing software solutions.

CAC 3. Communicate effectively in a variety of professional contexts

2 System Description

The following sections describe the specifications that were formulated as a result of communication between Team 3 and the SoFab Inks team.

[1]Database term for Create, Read, Update, Delete.

2.1 Needs Assessment/System Requirements

Following assignment to this project, the team assembled and met virtually with the SoFab Inks team for brief self-introductions, an overview of the current issues facing SoFab, and to gain an initial insight of what the SoFab team was looking for in a solution to these issues.

The SoFab team described the current state of inventory management at the company which included problems such as shipments arriving to incorrect customers, an inability to pinpoint important information about products as they progressed through the manufacturing process, and difficult to track remaining volumes of chemical products. In these discussions, SoFab also emphasized the importance of a solution begin *simple and easy-to-use*. As the team is primarily constructed of chemical engineers or business people, technology was not a strength.

The company also made it clear that the ability to generate item labels for internal tracking of should be a priority. These labels would allow members of their team to easily scan a barcode to view the details of an item. Finally, it was also made clear that the company also desired the ability to generate shipment labels for their products as well. These labels would differ slightly from their internal tracking label counterparts with the inclusion of chemical hazard information. This information would be included as a way to reduce harm for customers handling SoFab's chemicals upon receipt.

After this initial discussion, Team 3 began to brainstorm potential solutions to the problems presented. Immediately, 3 main pieces of software jumped out at the team as critical pieces to what would be the final product.

1. **A Database System** - In order to move the company away from the usage of Google Sheets and toward a more efficient, safe and redundant, user-friendly solution, Team 3 knew it would be necessary to select an existing database software solution. While the team was unsure of what specific solution would be chosen, it was sure that one of these solutions would be required.
2. **A User-Friendly Database Interface** - While a database solution would be an incredible improvement on its own, it would be useless to the SoFab team if there were not a simple and easy way to interact with the underlying data. Again, the team was unsure of what specific solution would be chosen, but a few requirements from discussions with SoFab were clear.
    - **Clean, Simple, Easy-to-Use** - As previously discussed, SoFab was clear that a simple and easy-to-use solution was of paramount importance for the day-to-day usage of the product.

- **Free and Open-Source** - While this requirement was not mentioned in the initial discussions with SoFab, this requirement jumped out as important to Team 3 because this would help to avoid incurring additional costs beyond the development cost that SoFab had already paid.

3. **Software to Generate Internal and Shipment Labels** - After discussing the need for barcode and label generation software, the team found that it would likely be necessary to build custom software to meet the needs of the client. The requirements were quite specific, and would not be available in any existing commercial product. These requirements certainly would not be made available in any *free and open-source* software.

2.2 Initial System Specification

Following the identification of the 3 main categories of software that would comprise the solution to SoFab's inventory management problems, Team 3 dove into research of each individual component to identify optimal selections.

2.2.1 Selecting a Database

Firstly, it was important for Team 3 to become familiar with existing solutions that were **free and open-source**. This required conducting research on computer-science related websites and forums, and more general forums like Reddit. While a site like Reddit may not always be the most reliable source of information, it could provide a general sense of what people feel about particular software and how easy it is work with.

Many databases fulfilling the free and open-source requirement were identified, including: PostgreSQL, MySQL, MariaDB, and SQLite. As many options were available to select from, it was important to look beyond this requirement and investigate techinical specificaitions of these solutions. During this time it was discovered that **PostgreSQL** had several technical benefits over more popular rivals. PostgreSQL boasts of being a fully **ACID** compliant database system. With features such as *Write-Ahead Logging*, which writes transactions to a log file to avoid pushing a full table(s) every time a transaction is committed, *Multi-version Concurrency Control* which the PostgreSQL documentation describes as

> "This means that while querying a database each transaction sees a snapshot of data (a database version) as it was some time ago, regardless of the current state of the underlying data. This protects the transaction from viewing inconsistent data that could be caused

by (other) concurrent transaction updates on the same data rows, providing transaction isolation for each database session."[2]

Furthermore, PostgreSQL utilizes its *Write-Ahead Log* to implement *Point-in-Time Recovery* without the need of complete backup. Additionally, since the Write-Ahead Log contains all transactions since the previous system backup, one can return to the exact state of **any** *point in time* between the most recent backup version and the current version. Team 3 felt that these benefits would be incredibly beneficial for SoFab's new database, which would be the central hub containing the whereabouts and remaining inventory of their lab. This database would also contain important product information which if lost or damaged could have severe consequences for their business.

Beyond technical considerations, ease of use was of great consideration when selecting a database, and luckily, PostgreSQL benefits from being very easy-to-use. PostgreSQL has an additional software called **PgAdmin4**, a project led by a core developer of PostgreSQL! This software integrates very well with PSQL[2] This software provides a GUI that allows developers to interact with the database, run queries, add and edit tables, view ERDs [3] for tables, and much more. This would simplify team members development tasks significantly and enable faster production.

For the reasons stated above, PostgreSQL was selected as the database software of choice for this project.

2.2.2 Selecting an Interface

While PostgreSQL would be a great choice to build a database for SoFab inks, this software alone - as stated previously - would be useless to the SoFab team by itself. Team 3 needed to produce a user interface that was simple, user-friendly, and would be capable of fulfilling all of SoFab's functional requirements. Team 3 scoured the internet, searching for a solution that would fulfil these requirements. Eventually, the open-source software Budibase was found. Upon investigation into Budibase, it was discovered that this software could be self-hosted, and if self-hosted, was *free-to-use*. This immediately fulfilled two requirements, so the team installed the software locally and began to interact with it to determine if it could fill the user-friendliness and functional requirements discussed previously.

It was found that Budibase functions in a manner similar to that of website builders like "Wix" or "Squarespace". An architect has the ability to connect to an existing database, then can select from existing templates based on the

[2]PSQL is short for PostgreSQL.
[3]ERD stands for entity relationship diagrams.

type of project at hand, and even use templates for types of pages to use. The architect can select between form-type templates where the user can edit or insert information about a row in a database table, or table-type templates where the user can view large amounts of data at a glance.

Additionally, one can drag and drop pre-made components from the sidebar, and arrange them as they see fit. These components can connect to any data source in the database. Data sources include standard database tables and even custom queries to provide maximum customizability.

While using a builder software like Budibase reduces the complexity in creating CRUD apps, they can pose a challenge in that all documentation and instructions for using the software provided strictly by Budibase themselves. The self-hosted Budibase community is not very large, so if an issue arises, an architect may be left to themselves to resolve it if that issue is not covered in the existing documentation.

Thankfully, however, the Budibase team has prioritized documentation, with instructions on how to use their many available components in various ways. They have created a page dedicated to the use of their platform, self-hosting instructions and guidance, component use, connecting the service to the database software in use, and much more. [3] The team also provides many instructional videos and how-tos on their website and on their company YouTube page. [4]

2.2.3 A Language for Custom Software

After selections were made for database and user-interface software, discussions were held on the topic of how the final major piece of the software stack - the custom label printing interface - would be constructed. Team 3 understood SoFab's requirement for this deliverable - that the software create printable labels to place on their inventory - but Team 3 imposed additional requirements that would support the team to fulfill the company's requirement. These requirements were identified as follows.

1. **Familiarity** - The most important requirement that was identified by Team 3 during these discussions was familiarity among team members with various programming languages. Due to semester imposed time constraints, it would be important to hit the ground running, without additional challenges of learning an unfamiliar programming language. A consensus was reached that team members all had prior experience with *Python*. This prior experience, paired with the languages intuitive syntax made Python an attractive choice with regard to this requirement.
2. **Community Support/Libraries** - Another important requirement concerning the selection of an optimal programming language to develop

this new software was community support and library availability. Once again, *Python* was identified as a language with great strength in this aspect. Python is known for its extensive library support, with over 589,000 projects in the 'pypi' Python package repositories. [5] Packages were identified that would allow Team 3 to easily generate barcodes, generate PDF outputs, and read from PostgreSQL databases. These features attributed to the appeal of Python for the development of this deliverable.

3. **Reliability/Durability** - The two requirements previously discussed were found to be great strengths of the Python language. However, an additional consideration for selection for this custom software was the durability of the language. A reasonable argument could be made that the responsibility of ensuring reliability and durability of code lies with the programmer, and not the language that a programmer may employ. However, humans have proven to be much less reliable than machines in many domains with defined rules.

   Recent developments in the programming domain such as the Rust language have built this fact of reality into the fabric of the language. These such languages provide memory safety by default, meaning that the programmer must have advanced knowledge of the language before performing potentially dangerous programmatic actions. Rust also provides an excellent ecosystem of tools such as 'Cargo' which both manages project dependencies and provides an easy method to run and test written code. Rust offers many benefits that Team 3 believed could be incredibly beneficial for a project that would need to be consistent and reliable day-to-day at SoFab Inks.

4. **Speed/Efficiency** - A final major consideration in choosing a programming language was the speed that the chosen language would provide after development. Performance is *always* an important consideration, but this was especially true with Team 3's plan to install many pieces of software on one machine on final deployment. On this point, Rust again was found to have great advantages. Compared to Python, Rust is far more efficient, as it is a compiled language. This means that at program run-time, no 'interpretation' of the code is required. This essentially shifts much of the heavy computational lifting to the code 'compilation' process, allowing the program to execute more efficiently at run-time.

Upon reviewing the major points of consideration, Team 3 decided that Familiarity and Comunity Support/Library availability were critical attributes in the lanuage selection process. While a language such as Rust provided significany boosts in execution time and Reliability, both of which would be beneficial to the end user, it was decided that the team had too little familiarity with this language. Learning a new language as a team would increase the complexity of the project too greatly, and endanger Team 3's ability to produce a satisfactory product on-time. It was for these reasons that Team 3 decided to

select Python as the language of choice for the development of this additional software, pending approval by the SoFab team during the next meeting.

(External design document) EAC 1. Identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics and CAC 1. Analyze a complex computing problem and to apply principles of computing and other relevant disciplines to identify solutions)

2.3 Final Specifications

Little changed with regard to the major required specifications of chosen software over the course of this project. While minor changes were implemented in requirements with regard to specific data tracking points or tracking methods, these could all be accomodated within the existing framework. For this reason the majority of the final technical specifications were set during the meeting that followed Team 3's discussion of initial specifications for the system.

Team 3 met with the SoFab team to discuss the specifications that Team 3 had arrived at as results of the prior discussions. The team wanted to ensure that these specifications aligned with the needs and vision of the company. Team 3 proposed the previously discussed database and user-interface solutions, with brief technical demonstrations showcasing the potential of these pieces of software as solutions to the inventory management problem. SoFab responded positively, with few notes with regard to the technical decisions reached by Team 3.

For these reasons the following selections were made final as software solutions for this project.

- **Database System** - PostgreSQL
- **User-Interface/CRUD Frontend** - Budibase
- **Programming Language for Custom Software** - Python

(finalized internal design document) EAC 1. Identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics and CAC 1. Analyze a complex computing problem and to apply principles of computing and other relevant disciplines to identify solutions and CAC 6. Apply computer science theory and software development fundamentals to produce computing-based solutions)

2.4 System Diagrams

Detail all interfaces between the environment and the components EAC 2. Apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors)

2.5 Hardware Overview Diagram

CAC 2. Design, implement, and evaluate a computing-based solution to meet a given set of computing requirements in the context of the program's discipline)

2.6 Software Overview Diagram

CAC 2. Design, implement, and evaluate a computing-based solution to meet a given set of computing requirements in the context of the program's discipline)

2.7 Economical, Technical, and Time Constraints

Over the course of this project, several constraints were imposed and revealed to Team 3 that limited the available tools for this project. These constraints fell under three main categories, each of which will be discussed in its respective section below.

2.7.1 Economic Constraints

Firstly, Team 3 experienced economic constraints, financially limiting software solutions available as tools for this project. Team 3 was limited economically primarily due to the identified requirement that utilized software be *free and open-source*. As discussed previously, this requirement was identified to avoid incurring subscription costs charged to SoFab following development of the project solution. This limitation significantly limited the software tools available to Team 3 for development.

Additionally, Team 3 was constrained economically due to the inability to provide development hardware to the SoFab team upon project completion. Unbeknownst to Team 3 early in the semester, hardware that was purchased to facilitate development of the project would be unable to be transferred to the on-site location upon completion. Luckily, the university approved the request

to transfer necessary hard drives containing critical database information upon project completion, but did not approve this request for other hardware necessary for this projects successful completion, such as a barcode scanner or label printer. For this reason the team was economically constrained and encouraged to develop a solution to SoFab's inventory management problem on the smallest budget the team could manage.

Similarly to the previous constraint, meeting this constraint would be important to ensure that SoFab would incur the smallest possible cost upon project completion. Team 3 wanted to deliver a project that contained as much of the desired functionality as possible, while avoiding extra purchases like barcode scanners or product label printers.

The team will expand on the specific solutions implemented to meet project requirements in the face of these constraints, however, the main ways in which economic constraints were addressed follow below.

1. Free and Open-Source Software
2. Software Implementation of Hardware Features/Creative Use of Existing Hardware

2.7.2 Technical Constraints

The next primary factor which constrained Team 3 during the development of the solution their technical ability and technological constraints. The limitations in technical ability discussed here coincide with time constrains, however technical ability specifically will be discussed in this section. As discussed in Section 2.2, Team 3 was limited technically in that all team members had the most familiarity with one programming language - *Python*. This imposed several technical limitations including reliability and efficiency that were traded for familiarity, ease-of-use, and library availability. The Rust programming language's memory safety features, combined with its status as a compiled language held much in the way of potential benefits for the development of this project. However, due to Team 3's unfamiliarity with the language, these potential benefits became limitations by use of Python, which faces challenges both with reliability and efficiency.

Additionally, Team 3 was consrained technologically by installation hardware. Upon completion, this project's software stack would be installed onto SoFab's main laboratory computer. This software stack would act as a server on the local area network to field requests from mobile devices for ease-of-use and convenience. It was for this reason that Team 3 was obligated to be mindful of resource usage regarding installed software, and aware of the computational cost of adding further software. The installation site would be used for other tasks

besides this inventory management system, and therefore the system needed to function efficiently to avoid slowing down other operations and tasks conducted on the lab computer.

Specific action taken to avoid concerns regarding these constraints is discussed in Section 3, however a general outline is provided here.

1. Mindfulness Regarding Existing Lab Hardware
2. Implementing Only Critical Software Solutions
3. Writing Efficient Python Code

2.7.3 Time Constraints

The main factor which imposed constraints on Team 3 during the Fall 2024 semester was time. The team had approximately 3 months to develop a solution that would satisfy the requirement of the SoFab team, and this meant that Team 3 needed to act fast to develop their product. This deadline itself imposed constraints on the team, such as how often and with what intensity the team needed to act, however it was also the primary factor in imposing technical limitation. Team 3 simply had no time to learn a new programming language comprehensively prior to implementing a solution. This was the driving factor in the selection of a familiar and well-supported programming language such as *Python.*

Furthermore, meeting dates with the SoFab team imposed constraints in that signicant progress was expected of the team approximately every 2 weeks, when meetings would occur. After one of these meetings had concluded, the team had 2 weeks to implement early versions of the discussed features to be showcased at the next meeting. This imposed an intensity that Team 3 needed to work with to be prepared for every meeting.

3 Detailed Implementation

The below sections include the specific actions and steps taken by Team 3 to develop the solution to SoFab Inks inventory management problem with project requirements and constraints accounted for.

3.1 Hardware Detailed Implementation

While the solution developed over the course of this project was constructed primarily of software components, some hardware components were required to meet and exceed the requirements of SoFab Inks. The primary hardware components are covered in detail below.

3.1.1 A Home for A Database

As discussed in previous sections, in order to develop software that improved significantly on SoFab team members experience of managing inventory, a database system was required. Once this was decided, the main point of emphasis was how to implement this requirement as safely as possible. Team 3 wanted to ensure with certainty that SoFabs sensitive and irreplaceable company data would be both secure and redundant to a avoid a catastrophic data loss scenario. This requirement however was not without mild cost.

The security of the database was a matter for the software implementation, however, redundancy required multiple storage locations to to ensure multiple independent copies of the database are available at any given time. For this reason Team 3 decided to purchase 2 1 Terabyte solid-state storage drives, intended to each contain separate copies of the database. One of these disks would contain the current working version of the database at all times, while the other drive would contain backups that would be conducted on a daily basis. The team could even write a script in such a way to keep record of each backup instead of overwriting the backup each day with the new copy. This would allow the team to inspect the database at any given point in its history if required.

Furthermore, investing in these drives at the beginning of the project lifecycle improved the experience of the transition to the installation site significantly. Because the team was able to develop the project on the purchased SSDs,[4] when the project was transferred on-site, the team could simply bring the drive containing the up-to-date software stack, point the lab computer to this disk, and have the project up-and-running.

3.1.2 A Barcode Scanning Interface

An additional piece of hardware needed to meet the full requirements of the SoFab team was a barcode/QR code label scanner that would allow the team to simply scan product to view their corresponding inventory details. While the SoFab team would be unable to keep the scanner that Team 3 purchased

[4]SSD is a computational term for Solid State storage Disk.

for development due to university rules, this product was inexpensive and in SoFab Inks' reasonble price range. The team conducted research into barcode scanning technology to discover what attributes made a good scanner.

Team 3 found that most barcode capable hardware scanners could double as QR code scanners, with little differences in feature sets between available models. For this reason the team sought an affordable wireless model that would allow SoFab to walk around their laboratory and scan products instead of being required to retrieve products first. The implementation of this barcode scanning technology required little beyond purchasing the product. Once received, Team 3 could simply plug the scanner's bundled USB dongle into any computer, scan a barcode or QR code while inside a text field, and the scanner would take care of the rest. This purchase made the development of this feature simple and instantly partially fulfilled a requirement set out by SoFab Inks for their inventory management system.

3.2 Software Detailed Implementation

The vast majority of effort expended by members of Team 3 this semester was in the domain of software. The team worked to utilize a combination of existing and custom-built software to provide an inventory management system that would satisfy requirements laid out by SoFab Inks. The individual pieces of software that played major roles in constructing this solution are discussed at length in the below sections.

3.2.1 A Home Development Server

Due to the nature of the software being developed, Team 3 identified a need to create a centralized server that would allow members to access the software from any location at any time. During the early weeks of development, the team was using existing tools and services to develop a solution such as PostgreSQL and Budibase instead of writing custom code. Development with these services would benefit substantially from running on a centralized server that could be modified by any team member. This would be far more efficient than developing solutions individually and compiling them into one solution at a later time.

An added benefit of creating a centralized server where all development would take place was that this server would closely mimic the conditions of final installation. Upon installation, the software stack would be deployed on a single computer that would serve all clients on a local area network. This experience would allow the members of Team 3 to work with an experience closer to that of an end user. This allowed team members to experience bugs that would appear at the installation site and fix them as they arose.

To construct a home server that would host all services required for this project and allow all Team 3 members access, a computer was set-up at a members home and given a static IP. This static IP would allow DNS services and the home router to find a constant path to the services to be accessed. Next, it was time to install all the existing services that would be required to develop the project. This software will be discussed at length in Section 3.2.2. All services were installed and initialized.

Next, a Nginx server running on another computer was configured as a reverse-proxy. A reverse-proxy is a service that acts as an intermediary for servers or services running on a local network. A reverse proxy intakes network requests and forwards them to the server where they are hosted. The benefits that a reverse-proxy offers to users is that only one port is required to be exposed to the internet. This reduces the number of open ports on a network, offering security benefits. Additionally, reverse-proxies can be configured to use HTTPS,[5] also enhancing the security of data *transmission*. Finally, reverse-proxies can also provide load balancing services, reducing strain on any one server on the network.

3.2.2 Docker-Compose

Docker - and its supplemental software Docker-Compose and Docker Desktop - played a pivotal role during the development of this project. Docker is a software that allows applications to be packed into 'containers'. This allows these pieces of software to run in isolation from other software, be more easily configured, and be isolated from the host system network which can enhance software security. While Docker containers share similarities with classical virtual machines in that they provide environments that are isolated from the host machine, Docker containers differ in a few major respects that are important to note in this context.

Virtual machines are known for the performance penalty that accompanies their use. This is because virtual machines are tasked with emulating an entire operating system, which is a very complicated and resource intensive task. Docker containers work to alleviate this performance problem by *sharing the host's operating system kernel*. This allows Docker to focus on the application software itself, without the need to emulate existing operating system features.

Expanding on these benefits, Docker-Compose provides the ability to roll multiple Docker containers into one centralized script, where all software to be used for a given project can be managed at once. One can specify version numbers, customize network configurations, assign storage mounts,[6], allocate

[5] Hypertext Transfer Protocol *Secure*.
[6] Storage mounts are locations in a computer where files are located.

extra resources, [7] and more.

The incredible benefits that this provides when developing an application to be deployed on another system cannot be overstated. What Docker-Compose allowed Team 3 to do over the course of this project is to develop a software stack with versions of software that were compatible with one another. The team installed this software on a Windows 11 machine to mimic the operating system in use at the site of eventual installation, reducing possible complications with system migration. Using these methods, Team 3 could be confident when the time for system migration came, that all software would be compatible and work together smoothly, keeping all existing data intact.

This technology removed a great burden from Team 3, and the effort placed into creating a stable software stack through Docker-Compose was rewarded upon migration to SoFab's laboratory in late November 2024. This will be explained in greater detail in a later section. The software that was integrated into this Docker-Compose stack included the database software PostgreSQL, the database management software PgAdmin4, and database frontend design software Budibase.

Most developers that provide the ability to deploy an application via Docker provide example Docker-Compose scripts defining the critical application configurations and environment variables to deploy the application. This was very beneficial to Team 3 for the development of this software stack, as examples for deploying PostgreSQL, PgAdmin4, and Budibase were found, accelerating deployment. [7] [8] [6]A sample of the final Docker-Compose Script is included below.

```
postgres:
  image: postgres:16
  volumes:
    - type: bind
      source: "D:/Docker␣Data/postgres_data"
      target: /var/lib/postgresql/data
  ports:
    - "5432:5432"
  restart: always
  container_name: postgres
  # set shared memory limit when using docker-compose
  shm_size: 128mb
  # or set shared memory limit when deploy via swarm stack
  environment:
    POSTGRES_PASSWORD: {POSTGRES_PASSWORD}
  extra_hosts:
    - "--add-host␣host.docker.internal:host-gateway"

pgadmin4:
```

[7] An example of an extra resource would be allocating GPU resources for a container.

```
20        image: elestio/pgadmin
21        restart: always
22        environment:
23          PGADMIN_DEFAULT_EMAIL: ${ADMIN_EMAIL}
24          PGADMIN_DEFAULT_PASSWORD: ${ADMIN_PASSWORD}
25          PGADMIN_LISTEN_PORT: 8080
26        ports:
27          - "0.0.0.0:8080:8080"
28        volumes:
29          - pg_admin_data:/var/lib/pgadmin
30
31  volumes:
32    pg_admin_data:
```

3.2.3 PostgreSQL

Once the Docker-Compose script was defined and all software was deployed on the home server machine and exposed to all Team 3 members, application specific configuration began for PostgreSQL. User accounts were created (Figure 1a) for each team member, and credentials were distributed. Team 3 then initialized the database for the project (Figure 1b), and set user privileges. PostgreSQL's user creation tool was utilized to add an additional account 'database dev' which would be given privileges to read, add, create, and delete on the database. These permissions could then be applied recursively to each user account, streamlining the permissions process.

```
inventory_management=# \du
                                   List of roles
  Role name   |                         Attributes
--------------+------------------------------------------------------------
 blake        |
 cj           |
 database_dev |
 hilton       |
 maggie       |
 postgres     | Superuser, Create role, Create DB, Replication, Bypass RLS

inventory_management=#
```

(a) Viewing existing users in the PSQL CLI interface.

```
inventory_management=# \l
                                                List of databases
        Name         |  Owner   | Encoding | Locale Provider |  Collate   |   Ctype    | ICU Locale | ICU Rules |   Access privileges
---------------------+----------+----------+-----------------+------------+------------+------------+-----------+-----------------------
 inventory_management | postgres | UTF8     | libc            | en_US.utf8 | en_US.utf8 |            |           |
 postgres             | postgres | UTF8     | libc            | en_US.utf8 | en_US.utf8 |            |           |
 template0            | postgres | UTF8     | libc            | en_US.utf8 | en_US.utf8 |            |           | =c/postgres          +
                      |          |          |                 |            |            |            |           | postgres=CTc/postgres
 template1            | postgres | UTF8     | libc            | en_US.utf8 | en_US.utf8 |            |           | =c/postgres          +
                      |          |          |                 |            |            |            |           | postgres=CTc/postgres
(4 rows)

inventory_management=#
```

(b) Viewing existing tables in the PSQL CLI interface.

Figure 1

3.2.4 PgAdmin4

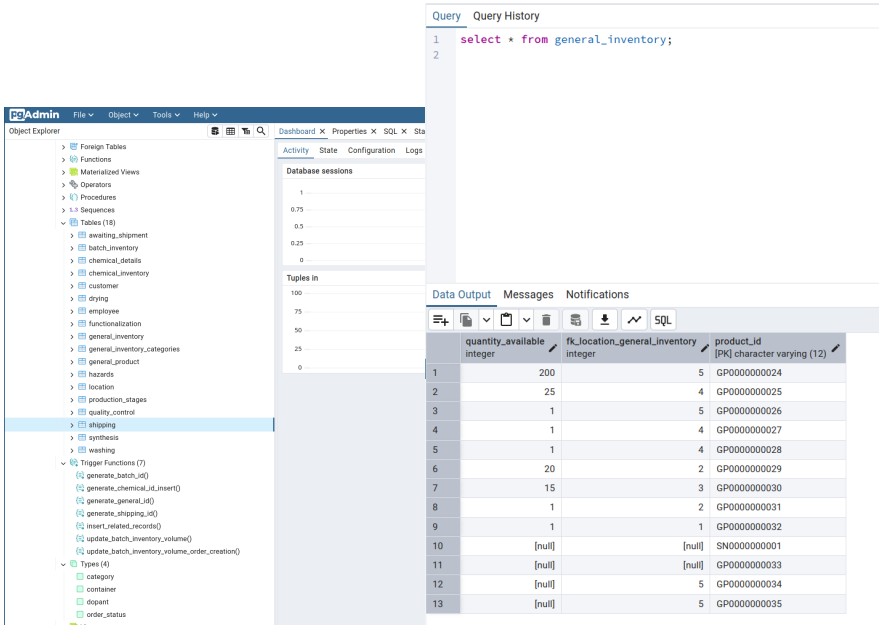
With the database initialized, the team could begin work on constructing a relational database in PSQL[8] that modeled the daily workflow in the SoFab Inks lab. However, Team 3 felt that it would be quite inefficient to develop in the PSQL CLI[9]. Members felt that it would be difficult to grasp the relations in a database and quickly view the attributes of a database with this interface. This would be especially true due to the length of time members had gone without working on database systems. Unfamiliarity would lead to frustration and confusion through this method of interaction. For this reason members of the team began to seek out another way to interact with a database system with a graphical user interface.

Quickly, members found that there existed a GUI[10] tool build specifically for PSQL called 'PgAdmin4'. Best of all, this software was developed by a core member of the PSQL team! PgAdmin4 boasted features such as graphical management of existing attributes including database schemas, tables, types, trigger functions, and more. This would allow the team to manage the database visually in a way that would allow members to quickly and easily learn the tools available at their disposal in PSQL. Additionally, this tool allowed for the execution of database queries, giving developers all the power of CLI PSQL in

[8] PSQL stands for PostgreSQL.
[9] CLI stands for Command Line Interface in a computer terminal.
[10] Graphical User Interface.

addition to the GUI tools.

PgAdmin4 was deployed in the project's Docker-Compose script and deployed alongside PSQL. Once deployed, user accounts were created and configured to access the PSQL database under these accounts. At this stage Team 3 could begin constructing the database while avoiding the overwhelming nature of a CLI tool to interface with the database system. Examples of the deployed instance after the insertion of tables can be found in Figures 2a, and 2b. More images can be found on PgAdmin4's webpage. [9]



(a) Viewing existing tables in PgAdmin interface.

(b) Running PostgreSQL queries inside PgAdmin4.

Figure 2

In regard to the construction of the database, the same general process was followed for three primary forms of inventory in use at the SoFab team's lab. These consisted in 'Product Inventory' which contained information about the company's products, 'General Inventory' which contained general lab items such as beakers and shipping boxes, and 'Chemical Inventory' which the company used as ingredients to their products. SoFab desired to have information about these items at each stage in their life-cycle. While this cycle changed depending on the type of inventory an item originated from, the process of creating tables to accomplish this effect would remain the same.

The general process follows below.

1. **Create a Table for the *Item*** - A table would be created for the type of inventory item, containing any *static*, or, constantly present, information about this type of item. This item would also contain the *ID*, which would be used to link each row, which represented one item, to related rows in other tables.

2. **Create a Table for Each Life *Stage*** - Next, team members would construct tables that represented a stage in a product's life. For example, the 'Product' inventory may have a product table containing the ID of this product, chemicals used to create this product, and in what amount, and other related information. Then, for each stage in a manufacturing process, tables could be generated that would track specific information about actions performed on the item at this step. This was an important attribute, as this would give SoFab the ability to easily review the histories of successful batches, and be able to recreate the product as closely as possible.

   Similar steps would be followed for other categories of items, tracking information at every step related to an item that was necessary as instructed by SoFab team members.

3. **Building Table *Relationships*** - An important last step in the creation of the database is creating links that connect tables together in terms of their relation to one another. This was generally accomplished by linked item IDs to each other via 'foreign keys', that helped the database understand the connections between different tables. A major benefit of this relation creation is that it enables automatic generation of ERD[11] diagrams. These diagrams aid developers by visually representing database tables. An example of an ERD for this database can be found in Figure 3.

[11] Entity Relationship Diagram.

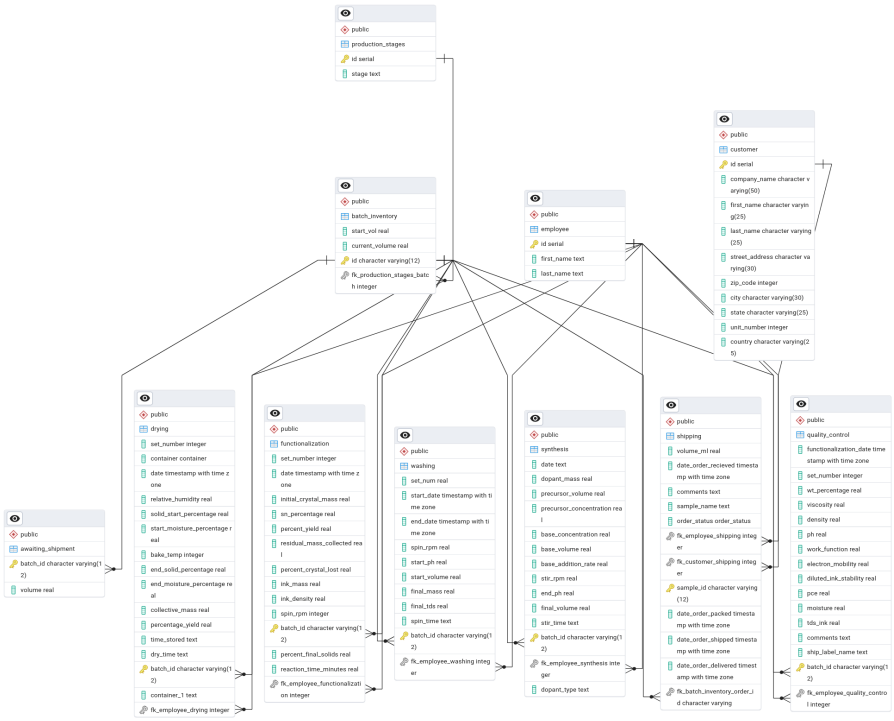


Figure 3: ERDs help developers understand how tables are related.

3.2.5 Budibase

Why Budibase? At this stage of development, Team 3 had constructed a functional database system that could store all required information for SoFab Inks' inventory. However, the current interaction system of PgAdmin, while helpful to developers, would be incredibly cumbersome for an end user to use on a daily basis. The methods by which items would be displayed would be confusing and generally unhelpful. For these reasons, it was necessary to add another software solution to the existing stack to enable SoFab Inks to be able to intuitively view the database entries, and better understand their data. The interface, as stated previously, needed to be clean and easy-to-use, free and open-source, and the added touch of a visually appealing system would be appreciated.

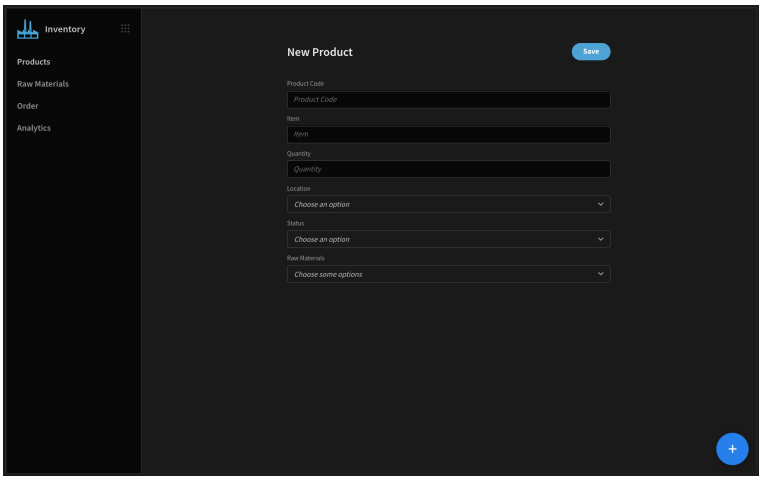
The team began their search into database systems with these constraints in mind. The requirement of a free and open-source system significantly reduced the available solutions for this deliverable, however one solution seemed to check all the required boxes. 'Budibase' is a company that produces a database CRUD software that allows users to easily construct clean, simple, visually appealing interface software. The company's software functions in a method that is similar

to that of website builders 'Wix' or 'Squarespace'. The software can connect easily to many of the most popular database software solutions on the market, including PSQL. Users have the ability to choose from existing template pages as a starting point and, from there, drag and drop any one of the many available data components into existing pages. These components can connect to any data source existing inside of the connected database including tables and, more importantly, queries. Queries allow users to construct custom tables that fit certain criterion in a database, and act as a kind of filter to find only data that contains specific values.

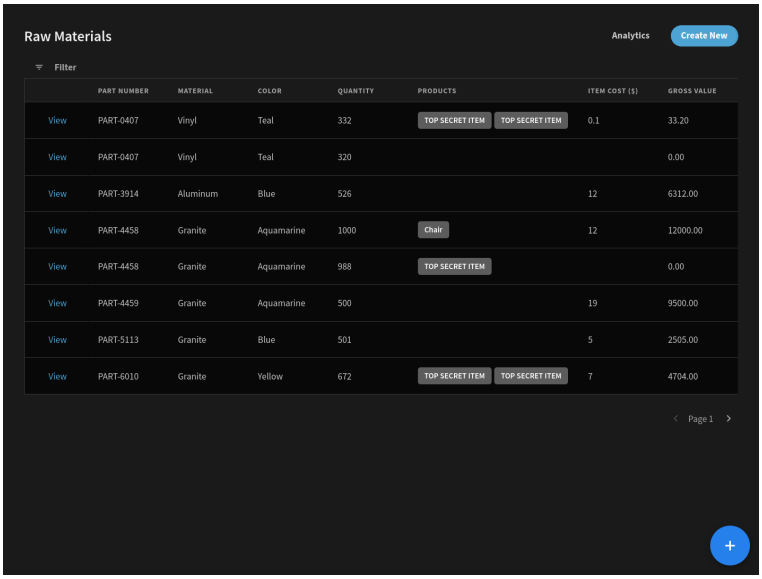
These technical specifications excited Team 3 as they would allow the development of an intuitive system and would provide a straightforward development experience. However, the most important requirement of the selected software were the cost of continued use and the open or closed source nature of the project. Luckily, Budibase offers a self-hosted plan which allows users to run the software on a local machine with up to 5 administrative accounts and up to 20 user account completely free-of-charge. Budibase is also open-source, and has a rich documentation on the Budibase website [3] and on the Budibase YouTube page. [4] These pages contain instructions and guidance for how to self-host Budibase, how to connect and use specific database software with Budibase, how to use the various components to build desired interfaces, and more. All of these attributes made Budibase a great option to develop an interface for this project.

Implementing Budibase Implementing Budibase into the existing Docker-Compose software stack was a straightforward process. This was mostly due to Budibase's provided documentation and existing Budibase Docker-Compose script. This script provided an excellent baseline to integrate into the stack, modify slightly, and deploy onto the home server. Once deployed, Team 3 members were given user accounts and access to the platform. Team members then worked to connect the existing PSQL database into the Budibase frontend by entering the Docker IP address, PSQL port number, and user credentials. At this stage users could begin developing web pages that interacted with existing data in the database, or insert forms that would allow users to insert data into database tables.

Team 3 searched available Budibase templates, eventually locating a template titled 'Manufacturing inventory app'. This template was perfect for this project scenario, and was selected and implemented into the self-hosted local instance of Budibase. Images of the template as found are shown in Figure 4.



(a) Insert new product template.



(b) View database table template.

Figure 4: The 'Manufacturing Inventory App' Budibase Template provided an excellent starting point for development.

Once this template had been downloaded onto the local instance successfully, Team 3 could modify and customize it to fit the needs of SoFab Inks. This would require replacement of all data sources with those found on the local PSQL server instance, as well as updating components and adding new pages to Budibase. This process began by implementing the 'Product Inventory' page,

which displays SoFab products at their current stage in the manufacturing process. The process includes multiple stages, and each product is displayed at the stage it is in. upon clicking a product, more details for the product are displayed. This page will also allow SoFab team members to view the remaining amount available of products, as well as allowing users to modify the remaining value as more is used or purchased. Products may also be searched on this page by ID to find the exact product a user is looking for. An image of the current state of this page is shown in figure 5

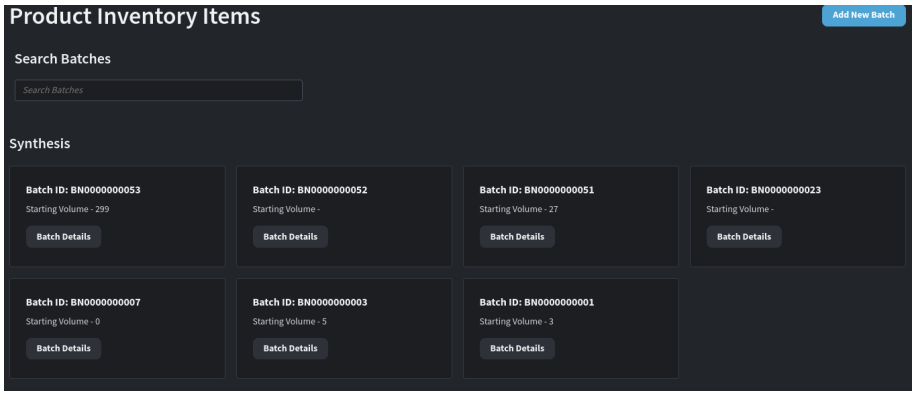


Figure 5: Budibase products page.

Following this implementation, similar pages were implemented for the other main types of inventory: general and chemical inventory. The process of developing these pages was very similar to the previous steps, however, and extra field was added: search by name. For these products, one may need to search by the name of a chemical or a specific product. Therefore, this feature was also included for these pages. An example of these pages is shown in Figure 6.

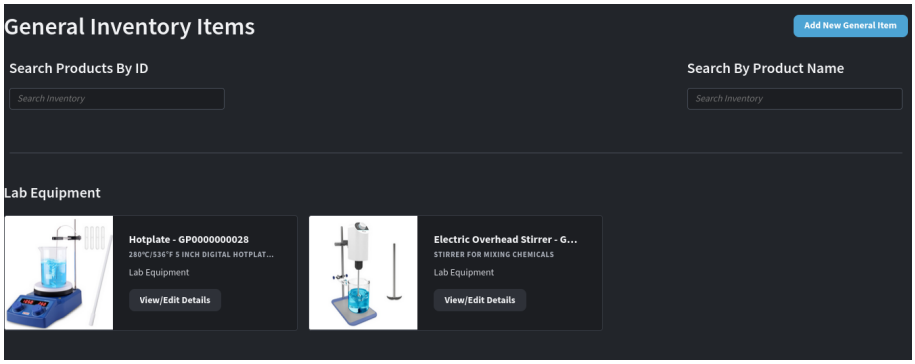


Figure 6: Budibase general products page.

At this stage of development, many of SoFab's requirements had been implemented into the database and the user-interface. However, in order to search a product in the front end, a user was required to navigate to that page and enter the ID for that *type* of item. This is because, in an effort to easily differentiate the different types of products, each of the three primary types of inventory items held barcode IDs with different three letter prefixes.

To make this experience more user-friendly, Team 3 developed a new home page for the Budibase front end which contained three simple components: a heading, a search box, and a QR code scanning component for mobile devices. This new home page would simplify the search experience, allowing users to find details about any product in the entire inventory. The result of these efforts is shown in Figure 7.

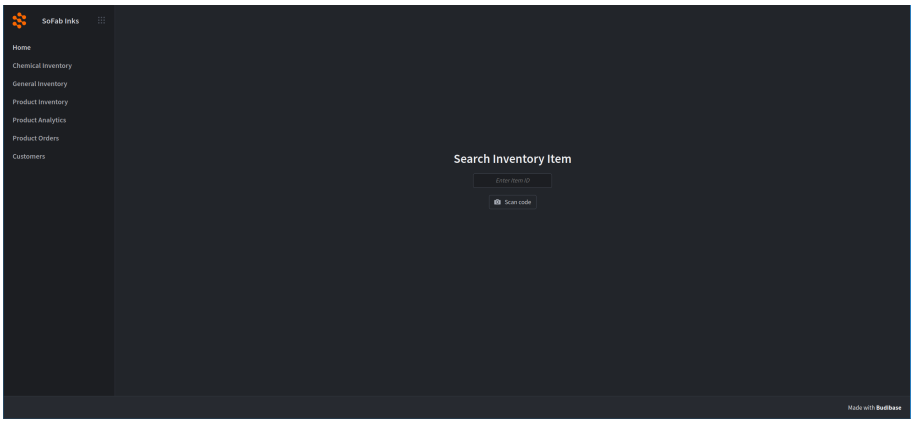


Figure 7: Budibase home page. Global search that searches all types of inventory via QR code or direct ID entry.

Finally, the last primary component developed on the Budibase front end was a page that would track the product orders received from SoFab's customers and what shipment stage [12]this order was in. Additionally, a customers page was added, allowing SoFab team members to view and edit customer details, as well as view each order received from a given customer. Images displaying these pages are shown in Figures 8, and 9.

[12]Shipment stages included: received, packed, shipped, received

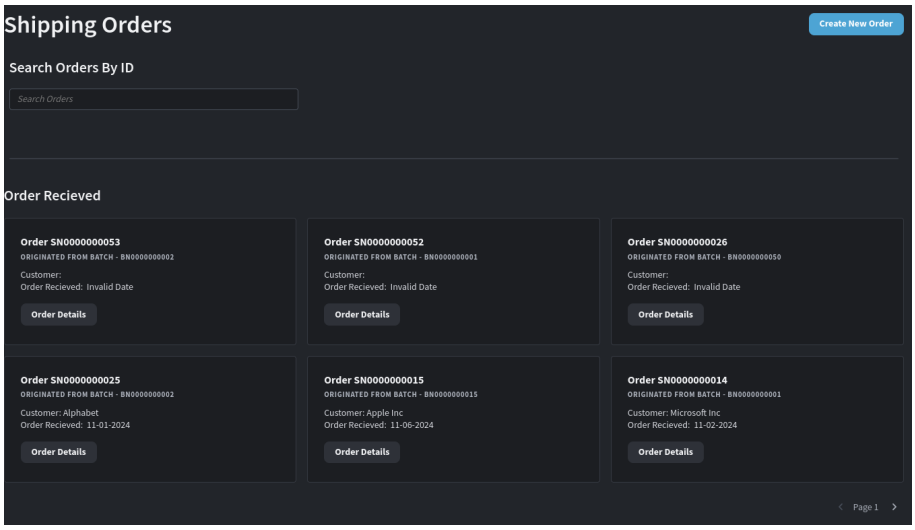


Figure 8: Budibase orders. Users may keep track of products ordered from this page.

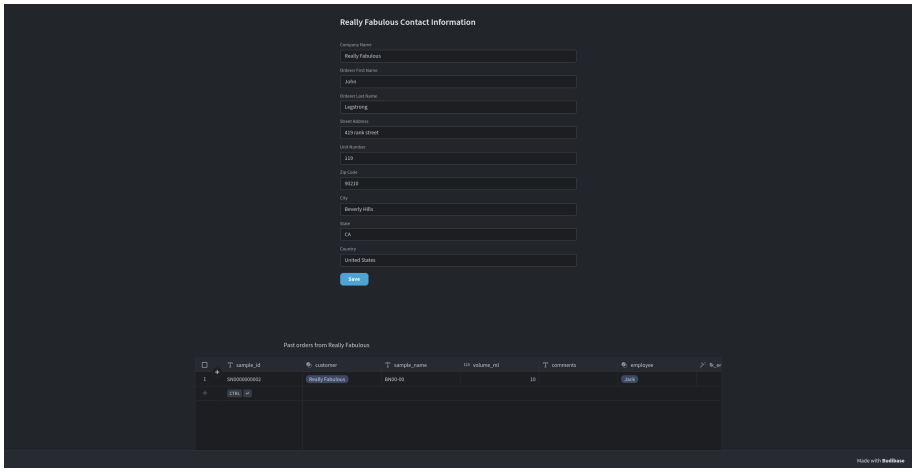


Figure 9: Keep track of customer information with Budibase. View customer information or view all orders originating from a customer

At this stage of development, all required functionality from the user-interface for PSQL had been achieved. SoFab would receive a database system that was user-friendly, easy-to-use, and that contained all required data attributes the company required.

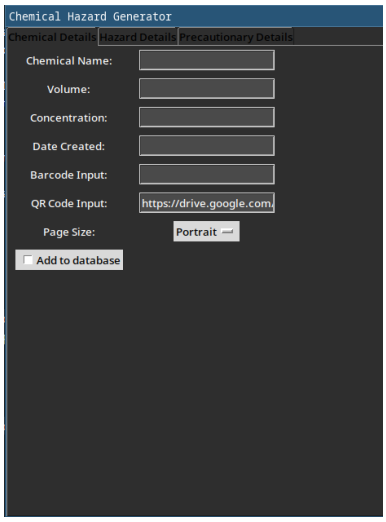
3.2.6 Python Database Insertion/Label Generation

The Python database insertion program was developed in parallel with the Postgres database and Budibase front end deliverables throughout the semester. At the outset of the semester, as discussed previously, the program was found to be necessary to implement features such as barcode and label generation to enable product tracking in SoFab's lab. This would allow for clear labelling of important hazard information, and significantly improve ease-of-use of the system by allowing users to scan barcodes to find details for items.

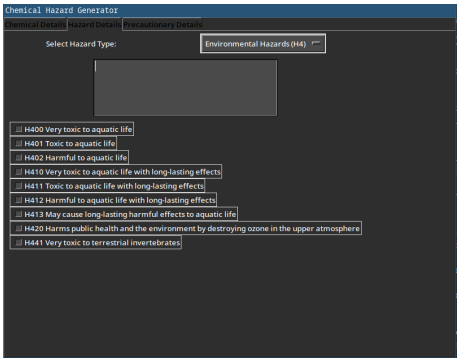
The first step in creating the Python application were choosing a existing GUI framework library that would allow Team 3 to quickly build a user-friendly interface. This would ensure that the SoFab team could clearly understand and navigate the application to remove friction from the inventory management process. After conducting research on various frameworks, and discussing within the group which frameworks team members were most experienced with, 'Tkinter' emerged as the leading candidate. Tkinter's extensive component library and community support allowed for near endless customization of the GUI, enabling Team 3 to create an intuitive interface fit to the needs of SoFab Inks.

Next, it was crucial to identify Python libraries that would enable generation of barcode labels and QR codes from a given input string. Team 3 identified the aptly named libraries 'barcode' and 'qrcode' that enabled this functionality. These libraries output .png files of images based on given input strings. With these libraries identified, Team 3 could begin development of the application. A simple interface was created allowing users to input basic information about products, including ID, name, date, and volume.

Additionally, in separate menus, a user could select applicable hazard and precaution warnings to be printed on a label to enhance safety both inside the laboratory and for customers receiving products. Once this information was input, a user could then generate the label utilizing the barcode libraries previously mentioned, along with various methods from the 'reportlab' library, including 'colors' for coloring, 'A4' and 'landscape' for PDF orientation options, and 'canvas' to organize the various components to be included in the label. Images displaying an early iteration of this software can be seen in Figures 10a and 10b.



(a) Early Python program home page. User can enter details of an inventory item.



(b) Inside the 'Hazard Details' tab, users can select applicable hazards.

Figure 10

At this stage of development, Team 3 had developed much of the desired functionality required by the SoFab team for the label generation program. With development time to spare, team members decided to improve upon the software by refactoring the codebase to adhere more closely to the model-view-controller architecture. This move would introduce a class based structure to the application that would enhance code readability, understandability, modularity, and enhance developers ability to modify and improve the code in the future. Classes would allow developers to radically reduce the number of global variables in the program.[13]

Team members worked to deconstruct the existing code into separate categories that represented specific functions of the code. Code that worked with GUI functionality were separated into a separate GUI[14], while code that handled data models was moved into a data group.[15] Finally, code that required interaction between data models and GUI components would be separated into their own category. [16] This restructuring allowed developers to easily navigate the folder tree to find code related to the functionality being searched for. This move improved development efficiency, allowing for more swift delivery of

[13]Global variables are frowned upon in the developer community, as they can introduce unnecessary complexity to programs.

[14]This group represents the 'views' group in MVC architecture.

[15]This group represents the 'models' category.

[16]This group is named the 'controller' category in MVC architecture.

features and debugging. An exerpt of this code structure is shown below.

```
class App(Tk):
    def __init__(self, controller):
        # initializing the Tk class instance
        super().__init__()

        self.title("SoFab Inventory Managment System")

        self.style = Style(theme="darkly")

        self.controller = controller
        self.controller.set_view(self)

        self.notebook = ttk.Notebook()
        self.notebook.pack(fill="both", expand=True)
        self.notebook.bind("<<NotebookTabChanged>>", self.
            on_tab_selection)

        # filling the notebook (top tabs) with frames

        item_type_tables = self.controller.
            get_item_type_tables()
```

```
class HazardPrecautionFrame(tk.Frame):
    def __init__(self, parent, controller, warning_dict,
        images=False):
        super().__init__(parent)
```

```
def generate_checkboxes(self, images=False):
    self.checkboxes_frame = tk.Frame(self)
    self.checkboxes_frame.grid(row=0, column=0)

    for item in self.warning_items:
        if images:
            image = Image.open(item[1])
            resized_image = image.resize((100, 100), Image.
                LANCZOS)
            image = ImageTk.PhotoImage(resized_image)
            item = item[0]
        else:
            image = None
        var = tk.BooleanVar()
        checkbox = ttk.Checkbutton(
            self.checkboxes_frame,
            text=item,
            image=image,
            compound="left",
            variable=var,
```

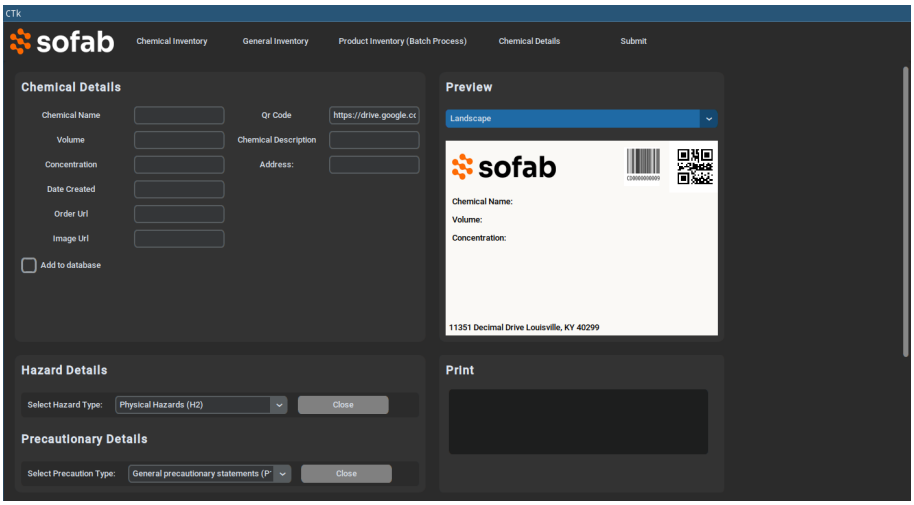
```
            command=lambda var=var: self.parent.
                update_text_box(),
        )
        checkbox.image = image

        checkbox.pack(anchor="w", fill="x")
```

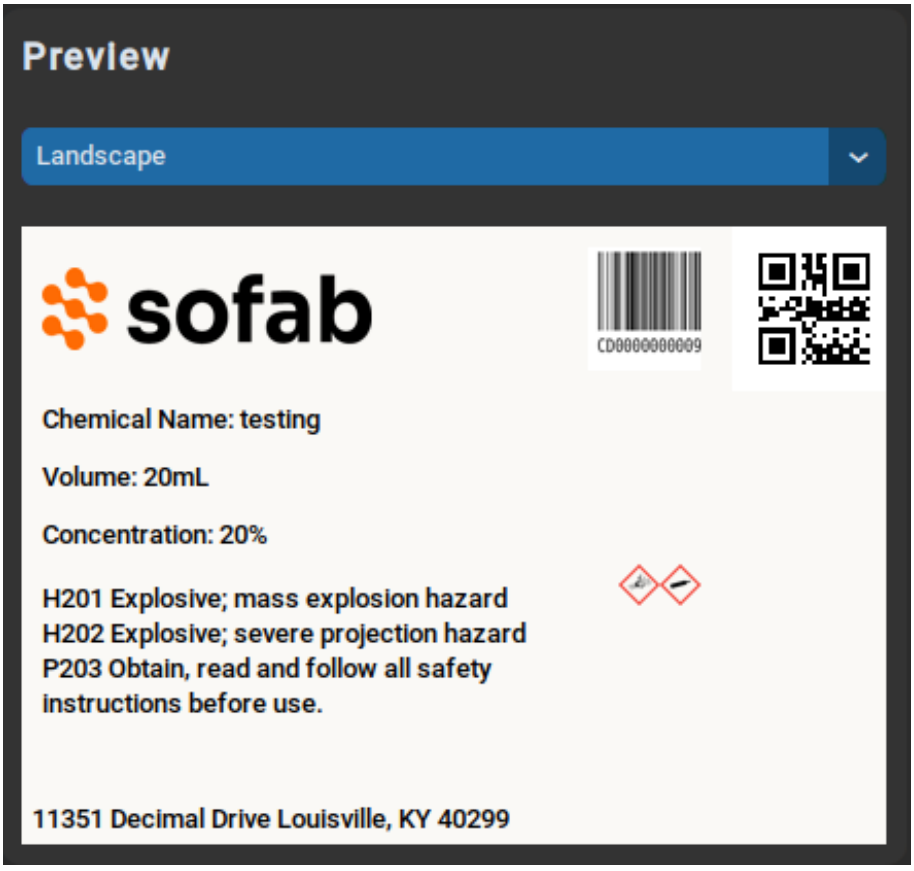
With all required functionality implented and development time to spare, Team 3 sought methods to improve the user experience of the Python application and more broadly the inventory management database system. Members tested the system, seeking weak points, or experiences that were less than optimal. One such experience was identified as the experience of inserting items into the Budibase user interface. While the experience itself was not unsatisfactory, the fact that one needed to insert this item into Budibase and, additionally, retrace these steps in the Python application to print a label was found to be less than ideal. For this reason, members searched for methods to accomplish two steps in one by inserting into the PSQL database during label creation. This would provide a smoother experience and save time for the end user.

To accomplish this, this the 'psycopg2' library was utilized. This library allows developers to connect to and execute PSQL queries to a database. Exceeding initial expectations, this library also allowed developers to generate dynamic forms in the Tkinter GUI by pulling relevant fields necessary for label generation from the database. This simplified the codebase, all the while allowing for the insertion of items into the database upon label generation. An extra GUI checkbox was added to allow the user to decline to insert an item into the PSQL database if so desired.

The last major development with regard to the Python program was a full scale GUI redesign utilizing the 'CustomTkinter' library. While the application contained all required functionality and more, the team thought that the software could benefit from a more user-friendly and intuitive design. Team 3 then got to work redesigning the interface with the discovered CustomTkinter library. This library allowed for simple customization of the GUI that was visually appealing and easy-to-use. Beyond redesigning the GUI for visual appeal, Team 3 added a component that allowed for a live preview of the label to be generated. This allows users to preview how a label would appear if generated at that moment, enhancing the clarity of the program. The results of this redesign can be found below in Figures 11a 11b.


CTk
sofab
Chemical Inventory
General Inventory
Product Inventory (Batch Process)
Chemical Details
Submit
Chemical Details
Chemical Name
Volume
Concentration
Date Created
Order Url
Image Url
Add to database
Qr Code
https://drive.google.cc
Chemical Description
Address:
Preview
Landscape
sofab
Chemical Name:
Volume:
Concentration:
11351 Decimal Drive Louisville, KY 40299
Hazard Details
Select Hazard Type:
Physical Hazards (H2)
Close
Precautionary Details
Select Precaution Type:
General precautionary statements (P
Close
Print

(a)


Preview
Landscape
sofab
CD0000000009
Chemical Name: testing
Volume: 20mL
Concentration: 20%
H201 Explosive; mass explosion hazard
H202 Explosive; severe projection hazard
P203 Obtain, read and follow all safety instructions before use.
11351 Decimal Drive Louisville, KY 40299

(b)

Figure 11

3.2.7 Deployment to SoFab Labs

The final stage in the development process was the migration and deployment of the software that was developed on the home server described in section 3.1.1 to the computer in SoFab's lab. This was a multistep process due to the nature of the project, with two primary deliverables developed through separate methods - the Docker-Compose stack and the Python program.

Installing Docker Software As described previously, all Docker-Compose software data was stored on the SSD drives for this project. This meant that Team 3 could simply transport these disks to transport the data. The other task necessary was to transport the Docker-Compose script which defined the software used, what version, mount locations for the data volumes, etc. This script was loaded onto a USB drive and transported to SoFab's laboratory. Upon arrival at SoFab Inks, the installation process for the software contained within Docker-Compose was a simple process. The detailed process follows below.

1. **Installing Docker Desktop** - First, it was necessary to install the Docker Desktop application. This download included all necessary Docker software including Docker and Docker-Compose.
2. **Install Windows Subsystem for Linux** - WSL[17] allows the use of software written for Linux to run on Windows machines. Docker utilizes WSL to run Docker applications. This helps to ensure cross platform compatibility of software from Linux to Windows and vise versa.
3. **Transfer the Data** - The drives containing the Docker volume data were installed into the lab machine. Next the Docker-Compose script was transferred from the USB drive to the windows machine.
4. **Modify the Docker-Compose Script** - Minor modifications were necessary to the Docker-Compose script to ensure that the system could find the modified SSD disk paths.
5. **Start the Containers** - At this stage, the software was installed on the system. The only necessary step was to run the command to start the containers within the compose script.

```
1         docker-compose up -d
```

Installing the Python Program Installing the developed Python program proved more difficult than the deployment of the Docker-Compose software

[17] Short for Windows Subsystem for Linux.

stack. In principle, the process would be similar to that of the Docker stack. First, the Python code was pulled from the GitHub repo that the team developed in during the semester. The packages used for the development of this project were previously frozen inside a 'requirements.txt' file, allowing quick and easy installation of all software versions utilized during development. The program could then be executed from the terminal. However, it was at this stage that a software bug was discovered affecting the label generation functionality of the program. The program raised errors regarding access to the PSQL database - which during design was intended to be separate functionality from label generation - that prevented PDF generation from occurring.

This led to a frantic, frustrating, and confusing debugging experience during installation at SoFab's laboratory. Ultimately, this bug went unsolved on installation day, preventing SoFab from using the software as intended until the team's later return to resolve this bug. This experience highlighted the importance of thorough testing that should be conducted prior to installation of a solution on-site. Team 3 plans to continue work on this project until this bug is resolved and the system can be used as expected.

Overall, the installation experience results were mixed. On the one hand, the deployment of the Docker stack was as smooth as possible, while issues were found during the Python transition. Team members found this a valuable learning experience for future projects, with a better understanding of how to prepare for these migrations.

4 Test/Evaluation Experimental Procedure and Analysis of Results

EAC 6. Develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions)

5 Societal Impact of Project/Legal and Ethical Considerations

include legal and ethical considerations

CAC 4. Recognize professional responsibilities and make informed judgments in computing practice based on legal and ethical principles)

6 Contribution of Project to Society/Expected Effects

CAC 4. Recognize professional responsibilities and make informed judgments in computing practice based on legal and ethical principles)

7 Engineering Standards, Constraints, and Security

EAC 1. Apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors)

8 Conclusions

9 Recommendations for Future Work

References

[1] SofaBinks. (n.d.). About SofaBinks. Retrieved November 29, 2024, from `https://www.sofabinks.com/about`

[2] PostgreSQL Global Development Group, *MVCC: Multi-Version Concurrency Control*, PostgreSQL 7.1 Documentation, `https://www.postgresql.org/docs/7.1/mvcc.html`, Accessed on: November 27, 2024.

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[9] pgAdmin Development Team, *pgAdmin Screenshots*, pgAdmin Official Website, `https://www.pgadmin.org/screenshots/#4`, Accessed on: December 1, 2024.

Appendices

A Customer Contact Information

B Data Sheets

C Additional Drawings and Diagrams

D Source Code

E Experimental and/or Simulation Test Results

F Software Installation Instructions

G User Manual

H Quotes, Including Ordering Information

I White Papers