ENGINEERING CHALLENGES AND SOLUTIONS FOR ENABLING THE AUTONOMOUS LABORATORY AT CARNEGIE MELLON UNIVERSITY

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In 2021, Carnegie Mellon University (CMU) started development of a unique LEED certified academic cloud-enabled life sciences and chemistry laboratory near their Pittsburgh, PA campus. CMU researchers began using the facility for experimentation in spring 2024.

In this type of space, laboratory experiments are not executed by actual researchers in the room, but through datasets and scripts that are remotely input through a software application and performed by highly-automated instruments with very little human interaction.

Such a facility gives researchers anywhere on the planet extraordinary access to the latest laboratory technologies that would be too costly in most circumstances. The idea is future forward, while also leveling the playing field for start-ups around the world. A researcher in Nairobi, Kenya could send an experiment via a software program that will be performed autonomously, with full documentation and reproducibility, in the CMU laboratory in Pittsburgh. It's an extraordinary leap forward for broad research access. The added benefit of this particular facility is that it is available to faculty and students, as well as private enterprise. The arrangement allows students access to cutting edge technologies and processes that will provide valuable experience before they enter the workforce.

This was a massive undertaking for the development of the physical laboratory space, and the technology infrastructure that would enable its use. Additionally, the allocated location for the laboratory was a warehouse that was previously used for campus storage. So, this was a warehouse conversion not a new build, which was another complicating factor.

The lab's unique space created extraordinary mechanical, electrical and plumbing (MEP), fire protection and technology infrastructure engineering challenges.

SPACE AND SYSTEMS PROGRAMMING

Evaluation of space use from the onset is extraordinarily important. What "departments" are going to possibly use the laboratory, both academia and commercial. Working with the University, Strada Architecture LLC (the architect) and contractors to obtain a detailed understanding enabled the proper establishment of MEP criteria. This included everything from temperature, air change, exhaust airflow rates, purified water, laboratory gases to power (normal and stand-by) requirements, through the utility densities for bench equipment. That criterion informed equipment selections and utility requirements and allowed for accurate equipment to capital budget ratios. The modular utility criteria reduced possible redesigns and provided full process documentation that will carry through for the lifetime of the laboratory.

To enhance the available research services, the facility included areas dedicated to more typical hands-on research in addition to the automated work cells. These spaces cover chemical and biological-based research, and include fume hoods, biosafety cabinets, glove box isolators and an NMR (nuclear magnetic resonance) spectrometer.

To achieve LEED Gold certification, the design team incorporated evoleEA to provide guidance and to challenge the team to include measures that would reduce energy and utilize sustainable materials.

SOLVING FOR REFRIGERATED MATERIALS STORAGE

One particularly challenging program element was the design and selection of the refrigerated vertical carousel storage units. To support the robotic-led research, a large inventory of common and not so common materials are required. These items are stored in bulk quantities within multiple vertical carousel storage units, several of which are refrigerated. The team and vendors for the cold room enclosure and vertical carousel storage units worked together to develop a custom design for a refrigerated enclosure that houses two vertical carousel storage units. The motorized storage units must operate within the extreme conditions present within the cold room enclosure.

Another challenge in the design was providing multiple access points within the cold room enclosure to align with operator access to the stored materials, as well as access points to the vertical carousel storage unit and cold room enclosure components, such as motors, compressors, fans, etc.   To maintain reliable service for their academic and commercial customers that will access the robotic laboratory equipment 24/7, the storage units (including the cold room enclosure equipment) are connected to stand-by power sources to ensure uninterrupted service.

Utilizing shared documents on-line, the team worked in a collaborative environment to jointly develop the program requirements, including laboratory and robotic equipment. Most often, the University would provide information regarding the equipment which Strada and Bala used to research current selections as well as to determine dimensional data and utility requirements.

BRINGING DATA CENTER TELEDATA AND POWER INFRASTRUCTURE TO LAB ENVIRONMENTS

Being a robotic research facility which relies on Internet traffic to direct the research being conducted, the teledata and power infrastructure begins to resemble a data center. The power load dedicated to this facility is 30 watts per SF to accommodate lab and server equipment. In comparison, a typical lab will be provided with an average of 15 watts per SF.

Another feature of the electrical and teledata systems are robust distribution paths, consisting of modular raceways and cable trays routed throughout the research space. Compared to a typical laboratory, additional space was dedicated for multiple server rooms to handle the Internet traffic and internal communication with the robotic equipment. To enhance reliability, redundant power supplies were provided. As these types of facilities continue to evolve, they will merge additional data center technology into their designs.

INCORPORATING ADAPTIVE MODULES

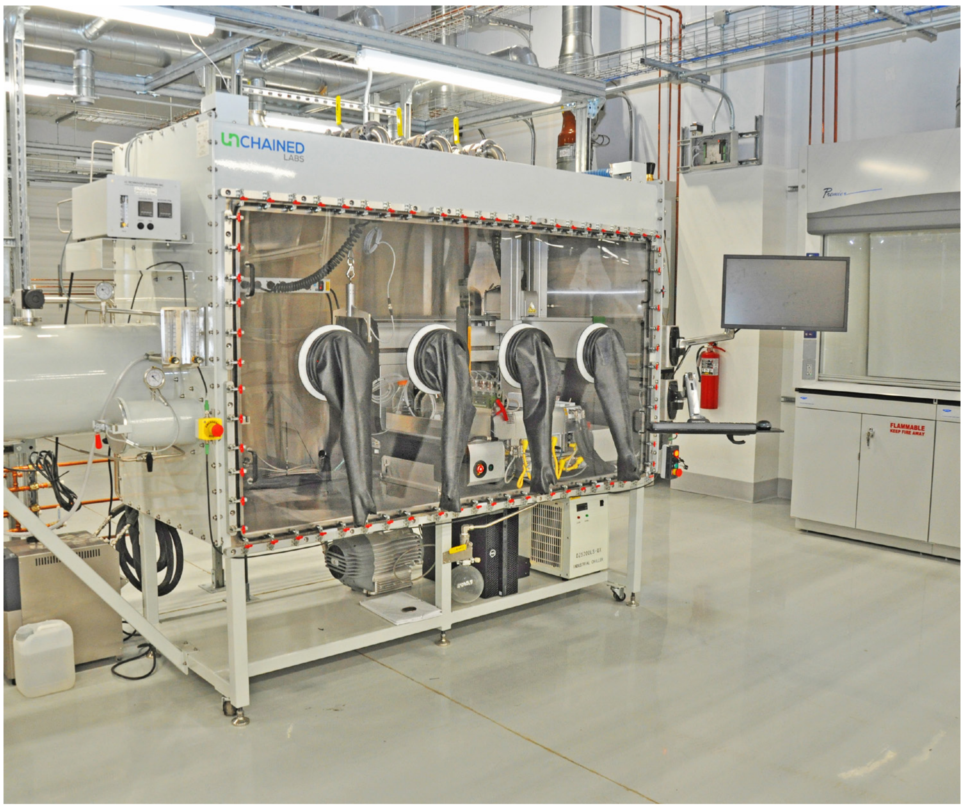
Lab flexibility is a necessity when a research experiment can come from a diverse group of people from anywhere in the world. Essentially it needs to be pod-based. Each pod needs the right combination of primary and supporting laboratory equipment on a series of benches, with supply lines for utilities – laboratory gases, electric, water, exhaust air and teledata for robotic access to the communications network. Each pod could have a specific use, or specialty, which modifies those supply needs, or they can be configured to do it all in one location. This is where space programming comes back into play.

To provide flexibility, multiple pods were developed to house individual benches. The benches have been aligned in rows to maximize the available space for research. Each bench is moveable casework and may be removed to accommodate floor mounted robotic equipment, when bench mounted robotic equipment is too small for the research desired. This alleviated the need to dedicate specific pods for larger robotic equipment. The utility infrastructure consisting of point exhausts, lab gases, power (normal and stand-by), and data was configured to supply each pod without restricting access, and was installed in a modular fashion so that each pod receives the same MEP utilities, providing ultimate flexibility.

HAZARDOUS ANALYSIS

To maximize the flexibility of the research area, it was developed as a large, open laboratory space. As such, that presented challenges to control the use of flammable and oxidizing liquids and gases, without limiting functionality within the laboratory. The design allowed for increased usage of these compounds by allowing for sufficient quantities to be used throughout the research area. This was made possible by incorporating dedicated storage areas within the facility to segregate high densities of stored hazardous materials. Dedicated flammable storage cabinets are located within the laboratory space. Further measures include a segregated fire protected room to store flammable liquid waste and storage of flammable laboratory gases within another segregated room.

Additionally, typical safety equipment was incorporated into the design to allow staff, faculty and students to handle hazardous compounds. Personnel protection is provided by fume hoods, biosafety cabinets and glove box isolators. These devices safely separate users from hazardous and toxic compounds when they must be handled.



To provide a unique research benefit, the facility houses an NMR spectrometer to offer an advanced chemical analysis tool to their customers. The NMR unit utilizes cryogenic fluids to cool its magnet, which creates a hazard if accidentally vented into the room. The mechanical system surrounding the NMR unit was designed to remove these gases through the use of elevated ventilation air and strategic placement of exhaust grilles to capture lighter than air gases that rise and cold gases that will sink to the floor.

WAREHOUSE CONVERSION

As mentioned, the CMU autonomous lab is located in a warehouse which was not originally designed to handle the intricacies of lab infrastructure. This use requires analysis of roof structure and weight bearing capacities for exhaust fans and stacks, energy recovery equipment, and custom air handling units. As a warehouse, the building roof structure is minimal and not well suited for the heavier equipment loads associated with a research facility. The team worked to provide adequate space within the building and outside to accommodate the necessary MEP equipment on grade, while strategically reinforcing specific sections of the roof structure to accommodate the large exhaust fans and energy recovery equipment required to be mounted on the roof.

Plumbing natural gas, water supply and sanitary waste capacities provided for a warehouse are minimal. This research facility requires capacities that are exponentially higher and more complicated to distribute. However, efforts were made to work within the confines of the existing utility size limitations. Storage techniques were employed for the water systems, including purified water and waste, to periodically hold and buffer the intake and discharge rates into and from the existing infrastructure utilities.

Electrical power supplied to the warehouse was insufficient to accommodate the research function required. The addition of automated robotic equipment and advanced data communication equipment requires elevated power loads. It was necessary to bring a new power supply to the facility to meet the unique demands of this facility.

SUMMARY

From the outset, it was clear that this would be no ordinary lab to develop. Nothing was standard. This laboratory would inspire worldwide creativity and scientific exploration to enable solving the world's most complicated problems. Starting from the basic warehouse structure and moving through the complications of integrated pod modules, refrigerated and hazardous materials storage and access, to the teledata requirements of receiving and conducting the experiments from anywhere on the planet, this was groundbreaking territory. Working with the teams from the University, Strada, evolveEA and vendor communities required massive coordination along with a singular focus on creating a blueprint for the future of laboratory development.

WANT TO KNOW MORE?

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