Mission Impossible

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Design Prompt

In today's world, the COVID-19 pandemic has affected all of the lives and forced us to take safety precautions like never before. However, doing so has pushed businesses to their breaking point, with movie theatres taking one of the hardest losses during the pandemic. Therefore, we felt that designing an environmentally friendly theatre minimizing germ propagation using filtration mechanisms would make for a great project, as it would help struggling businesses, and give people a chance to enjoy a day outside, safely!

With safety being the highest priority, we knew that we would have to incorporate air ventilation systems, contactless food delivery networks, and at the heart of it all, a fun and lasting memory. These goals left the team with plenty of tasks and obstacles that we had to sort through. Starting with air ventilation systems, we had to ensure that air within the theatre was constantly being filtered and circulated to reduce the risk of transmission of the coronavirus. Next, we had to design a functional and contactless food delivery network. The primary functions of the robot would consist of travelling from the concession stand directly to guests, while simultaneously avoiding its surrounding obstacles, such as people, trash, and miscellaneous objects that can create safety hazards. Furthermore, with these overall designs incorporated into the traditional movie theatre, the team presents the "COVID-less Movie Theatre".

Overview

The cinema industry is one of the worst hit industries during the pandemic as the people are being advised to stay indoors so that they do not contract the coronavirus. This in turn has had a vast impact on the cinema business owners and people at large. It is very necessary to come up with a solution to this issue and that is what the project Mission Impossible is all about.

This project aims to find a solution such that a movie theatre can be covid free and in turn give reassurance to people that they can visit the movie theatre fearlessly. This report proposes using hepa filters between the seats that could suck in the air that the people breathe out , filter it underground and pump the filtered air back in the room. This would rescue the chance of spreading of the coronavirus upto 90%. The report also suggests using an automatic robot to serve snacks and drinks inside the movie theatre so that there is reduced human interaction which is one of the main reasons of contracting the coronavirus. We also aim at achieving a green energy solution by replacing air conditioners and electric coolers by making use of the natural environment surrounding the building and to use natural cooling mechanisms like passive and evaporative cooling whilst being mindful of cost effectiveness.

As a whole, Mission Impossible effectively provides a well sanitized and ecologically friendly theatre design.

Goal

The overarching goal of Mission Impossible is to build an effective, scalable, and cost-friendly movie theatre that could solve the issue of fear of contracting the coronavirus by going to the movie theatre during the pandemic.

Objectives

- (SNACKBOT) Design an automated device that could be used to deliver food and drinks from the concession stand to the customer seats.
- (MATCONTROL) Design the control center or 'brain' of the smart “Theatre Robot”.
- (THE BIOMIMETIC CINEMA) To present a design proposal of a two story movie theater that does not depend on air conditioners or coolers for the overall ventilation or cooling of the building
- (COVID WEB) Design COVID-free theater through a filtered system or device that captures the SARS-CoV-2 particles efficiently.

Design Breakdown

SNACKBOT

With the sudden rise in COVID cases, there has been a complete halt in people going out to movie theatres to enjoy movies. Not only has this decreased the business for the film industry but also taken a toll on normalising “sanitation and safety” while being present at a public place. Hence, the MAE committee’s goal for this year’s conference is to design a robot that not only moves around the movie theatre distributing snacks and drinks ordered by the customers but also provides them with sanitizer everytime it delivers the food . Moreover the overall goal of the project is to build a movie theatre that is COVID-free while keeping in mind the safety and satisfaction of the customers.

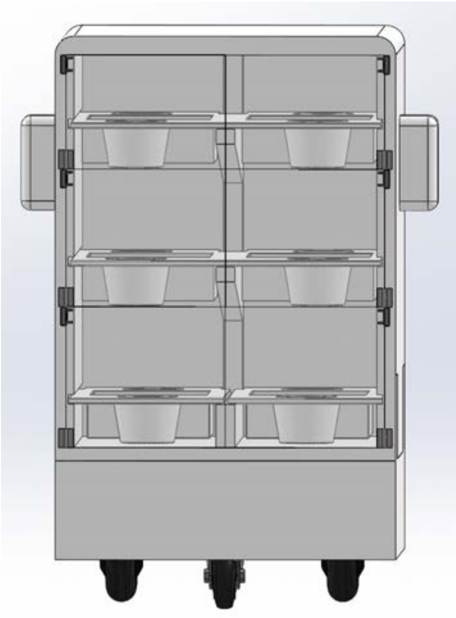
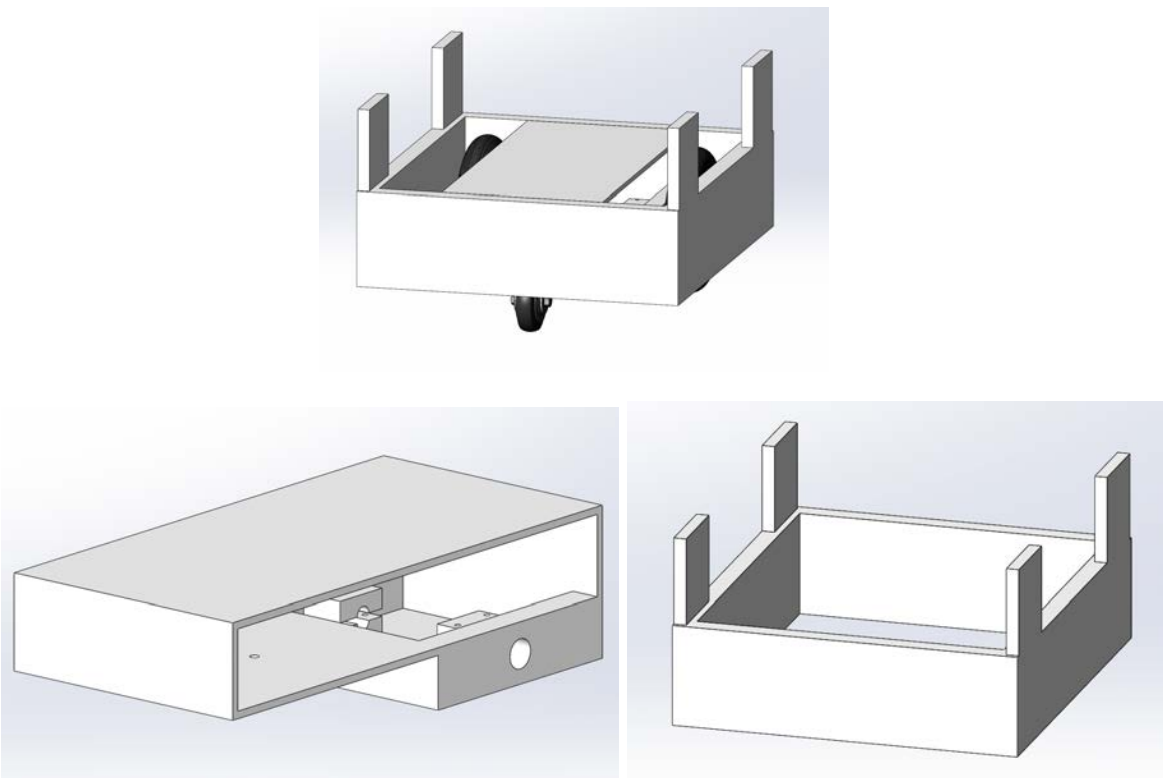


Figure 1. CAD of Snackbot

Mechanical CAD Breakdown

SolidWorks was utilized for both CAD and simulation for this project. SolidWorks was chosen for simulation so that the models did not need to be exported into another program. This made the iterative design process much easier and faster.

While designing the robot, the areas of focus were the base of the robot, the steering mechanism of the robot, the delivery system of the robot, the sanitizing function of the robot and the weight distribution throughout the robot.



B **C**

Figure 2. The base of the robot

The images in figure 2 above shows the base of the robot. This part of the robot is very integral to the overall design as this part houses all the mechanical and electrical components required to operate the robot.

This is the reason why the outer part of the base of the robot depicted by the image B in figure 2 is made out of sheet metal to protect it against any obstacles that might come in contact with the robot while it is moving through the movie theatre. The structures at the corners help in attaching the top of the robot to the base of the robot. This type of mechanism helps in the overall system efficiency as the top of the robot can be detached while refilling the orders and even if any technical maintenance is required the top can be attached to a different base while the damaged base is in repair.

The inner part of the base of the robot, depicted by the image C in figure 2 is a protective structure for all the electrical components such as the batteries , the wireless and path detecting sensors, the control for the motors and so on. This protection helps us in keeping the delicate sensors and all the electrical components away from any damage as a movie theatre is dark and in case of any accidents leading to the spilling of drinks for example does not lead to a short circuit. Having all the wires concealed inside the box leads to a cleaner design thus serving the purpose of avoiding accidents.

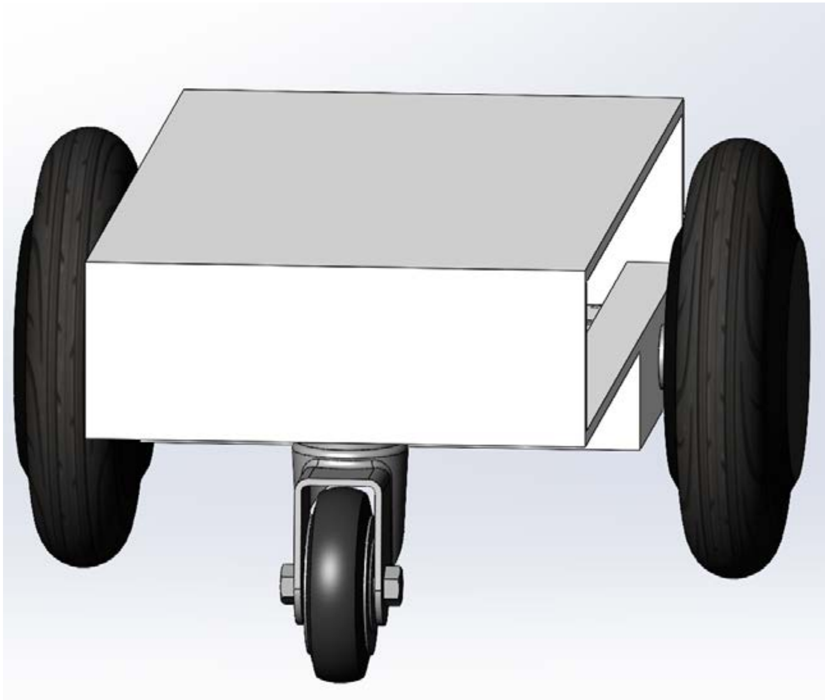


Figure 3. The steering mechanism of the robot

The robot is going to use a differential steering mechanism. It has two driving wheels at the back and one passive castor wheel at the front. The driving wheels at the back are going to steer the robot based on the velocity differential between the left and the right side thus making the robot rotatable.

The 6.5” driving wheels at the back are going to have a built in motor mechanism and are going to be bought off the counter. This kind of motored wheels was chosen as it would provide enough torque and power as required by the robot to drive at the required speed and at the required incline. Also, these wheels are cheap thus bringing down the overall machine cost. The 6.5” inches diameter of the wheels gives this robot a ground clearance of 1.25” thus helping it traverse over the small hurdles if any.

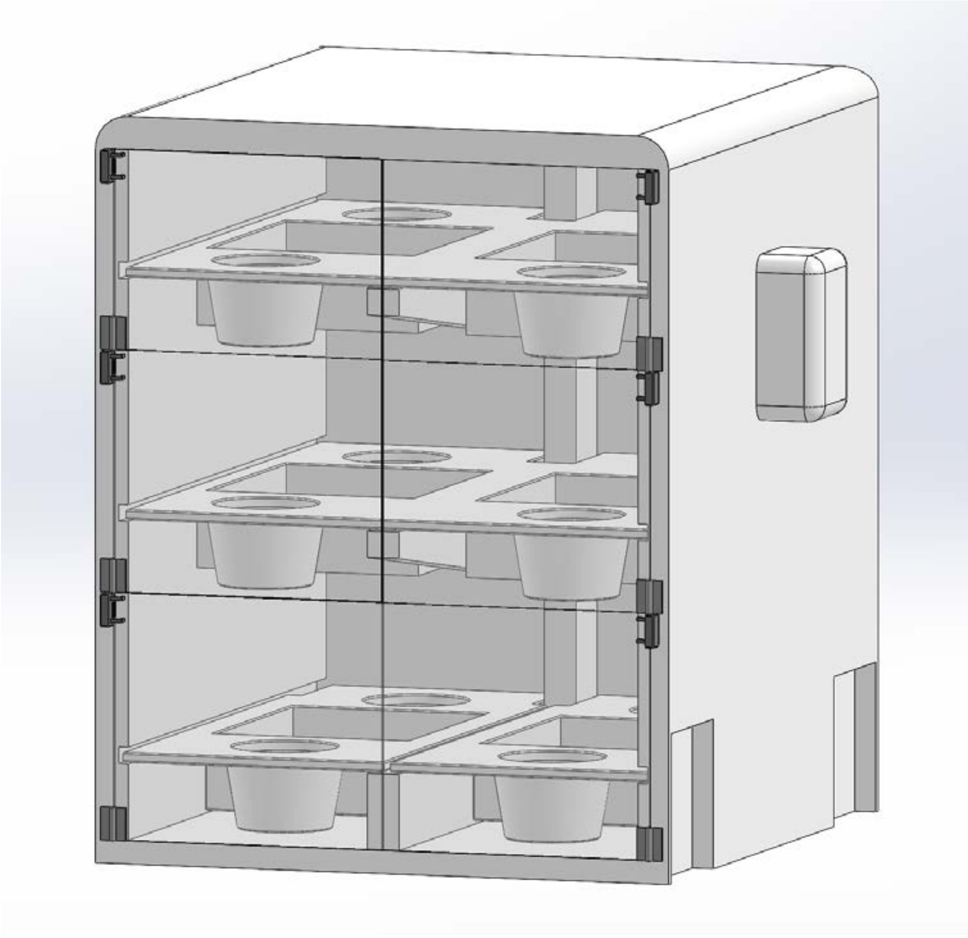


Figure 4. The top chassis of the robot.

The top of the robot is what essentially stores the snacks and drinks to be served. The trays filled with the orders are to be placed on the shelves in this robot. The top is designed in such a way that it can be detached from the base of the robot by just pulling it up. There are cuts on the fthe corners on the base of this part which slides in the fthe columns on the base of the robot mentioned above. This mechanism increases the efficiency as the person operating this robot does not have to bend everytime in order to put a tray in instead can just pull the top out and load all the trays at once. The maintenance of this robot also becomes easier as the top can just be detached and washed all at once. From the economical point of view, this design might also bring sales to the manufacturer as the movie theatres can purchase just the top separately or the bottom separately so that the robot can be used at all times even if one base is charging or if the top is being cleaned or if the either is under maintenance.

The top of the robot is also going to have LED lights situated by the walls so that the respective section would lit up when the robot reaches the particular customer seat making it easier for the customer to locate their order and not touch other things around and thus increases chances of germ propagation.

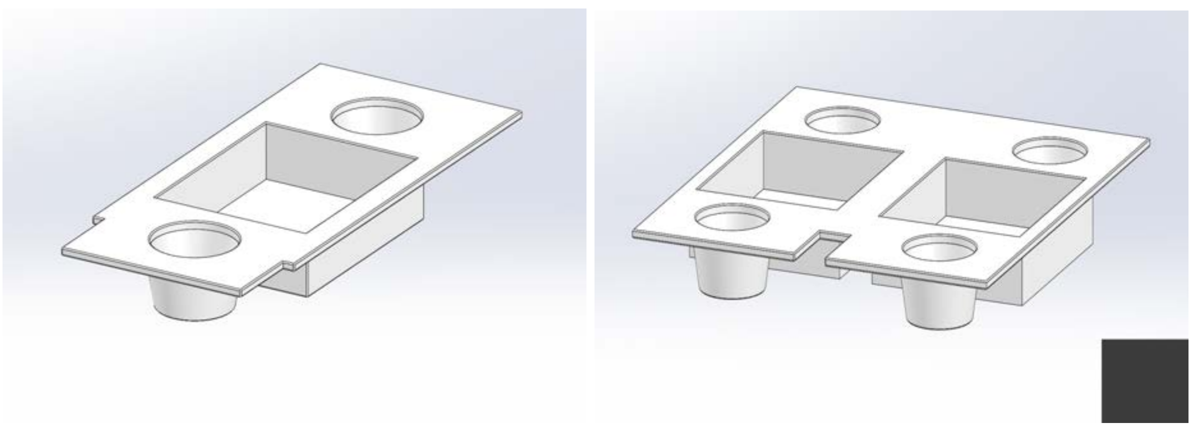


Figure 5. The removable trays

The order is delivered to the customer on these removable trays. The reason the removable design was chosen was to reduce germ propagation that would come along with serving different orders on the same tray. Thus this design of removable trays so that customers could pull out the whole tray designated to them and once they are done using the tray they could just keep it under their seats and the theatre employee could go around the theatre once the movie is over collecting all the trays.

The design of the top of the robot is such that it could take trays of varying sizes so as to not reduce the efficiency of the robot by using a big tray for a small order.

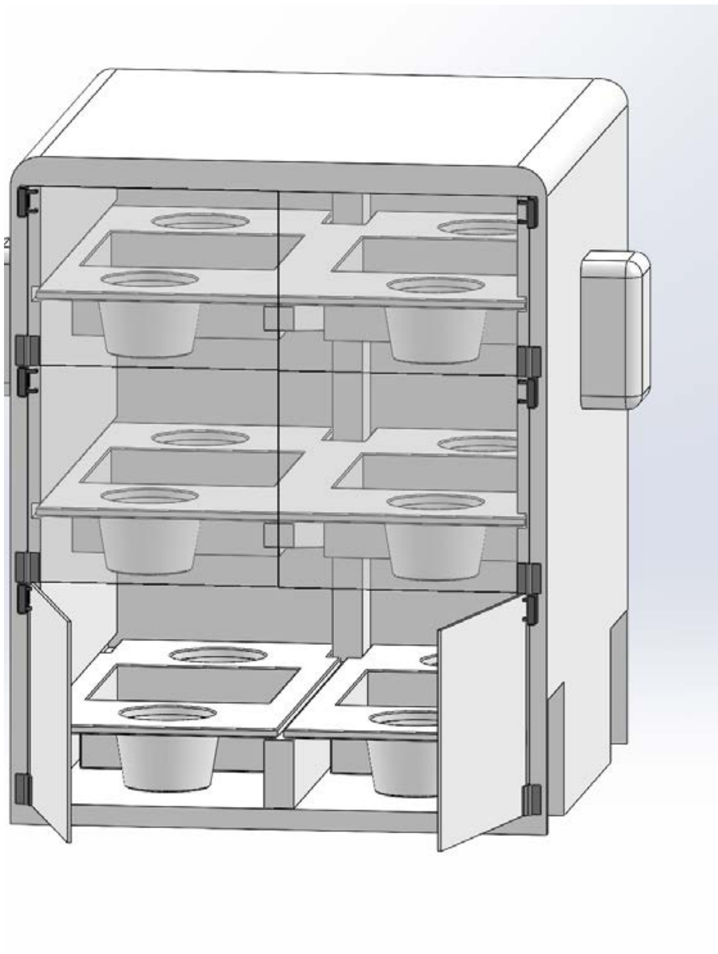


Figure 6. The automatic door mechanism

The robot is instilled with three motorized doors that would open with a tap on the mobile app. The doors on the robot are used to keep the trays from falling in case of travelling at an angle or even if the robot faces any obstacles. These doors would also isolate one order from the order and avoid any kind of confusion that the customer could encounter while pulling their respective tray.

Thus, as the robot will reach the respective customer seat the LED light for the respective tray section would lit up and a notification to have the door open would pop up on the mobile app so the customer could press on it and have the respective door open up.

Material Selection

As in nearly all engineering applications, the materials choice for the components plays a large role in the designing process. For this project, it makes sense to use as light weight elements as possible so that we can reduce the weight keeping in mind that the robot is strong enough to carry the required amount at the required amount of speed and acceleration most importantly along the incline. Due to its movement along an incline we want to design the robot in a way that its center of gravity is as close to the ground as possible so that it does not topple over while climbing or descending the incline. To reduce weight, the robot is made out of ABS as it has an adequate amount of tensile strength enabling it to carry the load yet being as light as possible

The doors of the robot are made out of acrylic. The team had three different options to build the door, which included acrylic sheet, plastic film and glass and out of the above mentioned options, the team decided to stick to the acrylic sheet because of various factors. According to the manufacturer of the Plexiglass, commonly called as an acrylic sheet, this item absorbs any impact such as accidental slamming on the door without cracking. By any chance, even if it breaks, the fragments are not sharp hence avoiding the possibility of any injuries. Another factor contributing towards this decision was the weight. Acrylic doors are lighter in comparison to a glass door and this also decreases the shipping costs of the raw materials.

The removable trays are made of HDPE. This decision was based on the amount of weight that the trays are supposed to carry and what is the nature of the weight. Since, the trays had to carry food and drinks, anti-toxic material was desired. HDPE was selected as while being cheap and light it provides us with the adequate strength and is also anti-toxic.

Integration with EECS:

The sensors and the coding of the wheels of the robot to follow a certain path to reach the designated customer while avoiding the obstacles on the way choosing the best path to take is to be taken care of by the EECS department. Besides this, the app that is to be used by the customers while ordering and opening and closing doors is also to be created by the EECS department.

Integration with CEE:

In cooperation with the CEE team, the design of the wheel hub and tire were chosen to be suitable for indoor use, such as on carpets and hardwood floors. After research, the decided it would be best to use rubber tires with grooves.

MATCONTROL

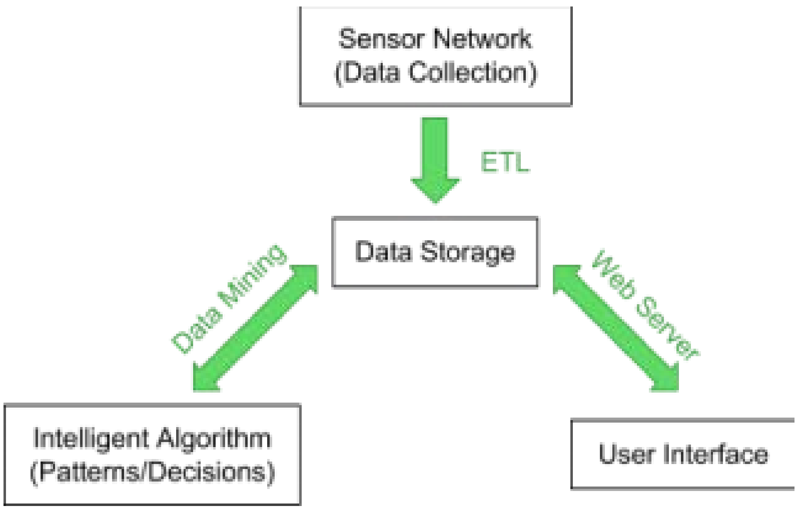


Figure 7. High-Level Process of Data Collection and Processing

The system utilizes learning algorithms to run on real-time data from 100 *SQ-SEN-200-DMK* sensors, 1 DynamoDB, 3 Indoor 120 degree motion sensors, 20 dome cameras, 1Dell Edge Gateway, as well as data stored in CAFM systems for all systems. The system that is focused on motion sensing makes sure that all devices are not overused to consume more energy than possible. Movement light sensors are shown to reduce energy consumption by 35 percent to a top of 75 percent, which will contribute to the energy conservation objective.

These results are easily achieved by large low-energy sensors distributed throughout the theatre (shown below).

As calculated from the different parts' specification sheets, the sensors are run on a low power system, the energy consumption of the sensors and controllers is calculated to be less than 2 mW hthe in the maximum demand of the system and spread all across the theatre to help the robot maneuver across the theatre.

Figure 8. Basic Theatre Layout

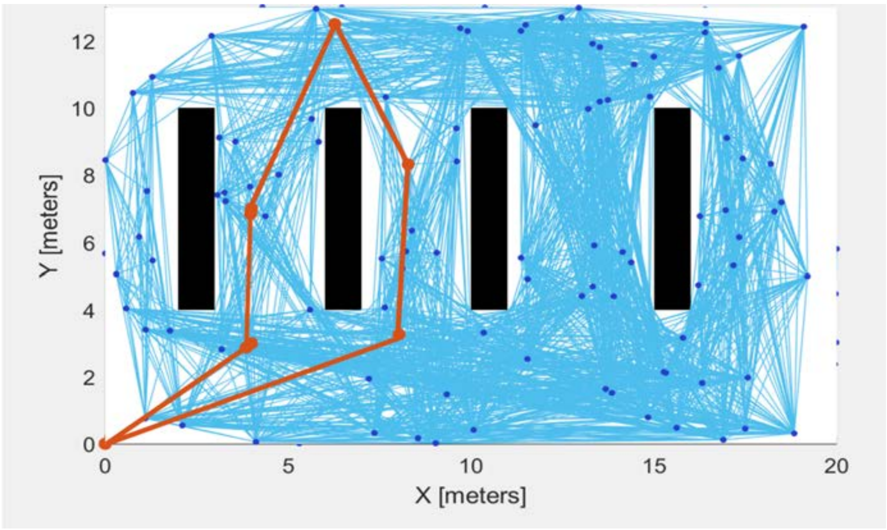


Figure 9. Dotted Checkpoints throughout the Theatre

Detailed Design Outline

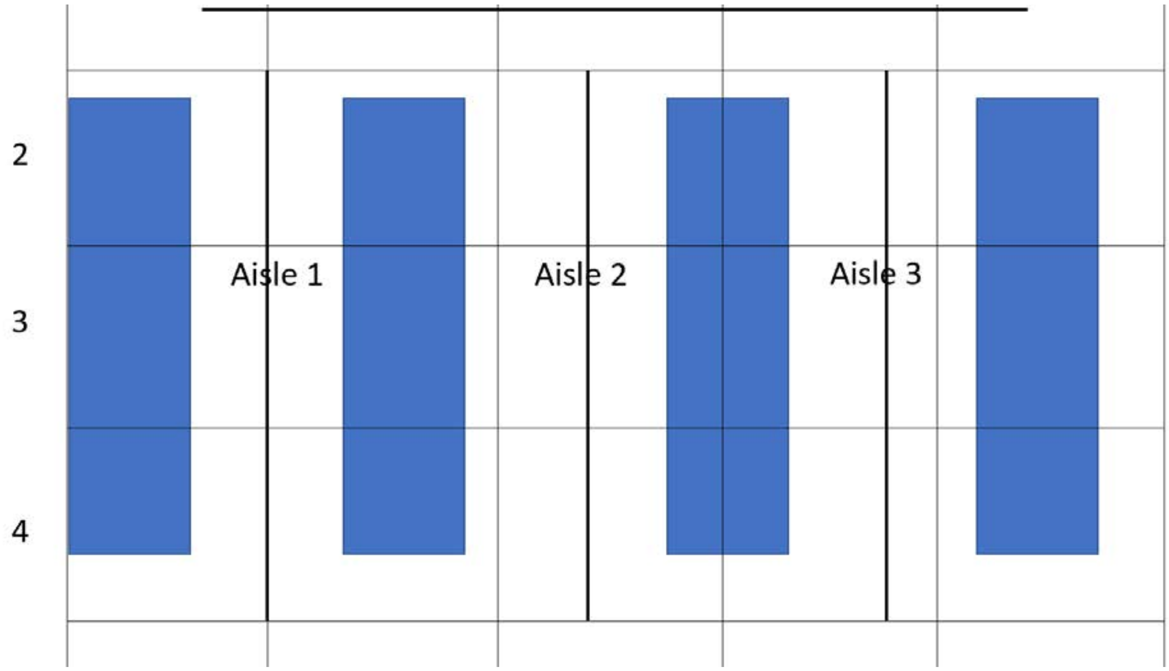


Figure 10. Sectioning of different aisles for easy motion.

the system determines 'smart pathways' as the robot 'learns' over time. We have chosen to use an unsupervised learning algorithm over a supervised learning algorithm because there is anticipated to be too much data for it to be labeled. The unsupervised algorithm will start receiving data from the robot sensors when it is unsure of how to deal with it. Over time it will build an understanding of its energy use and its occupants. The use of aisle mapping will separate data into sensible categories. Vectors that describe the personality of occupant and energy and time-efficient systems can be formed from the data can be handled accordingly. The algorithm will have specific goals that it will use to achieve optimal performance over time. The programmed goals are maintaining the productivity of the robot, reducing human contact, and also reducing the spread of viruses.

System Connectivity

Sensor Network

For the project, we will be AWS ElasticSearch (AES) to connect the network of sensors. AES allows us to easily create a user-interface and also is efficient in its power consumption. AES can be customized by creating different communication protocols, making it easy to connect with a variety of different sensors. The low energy solution is ideal for sending data infrequently over a range no larger than 40m. The sensor arrays will send radios to receivers on each floor that will be wired to a central computer of the theatre.

The following sensors will be included in each network:

- DynamoDB
- 120 Degree Motion Sensors
- Dell Edge Gateway
- Dome Camera

the key sensor will take images providing us with data such as robot location in Cartesian coordinates. To capture these images we will be using the Dome Cameras.

Data Storage

Once relevant data is determined, the AES controller will be able to send data to the database for further processing. The dataset obtained from sensors will come from monitoring stations in the theatre sectioned into 12ftx12ft areas. Dynamo DB will be used to store the data.

Once set up, a table is created based on the database schema to write data collected by the facility to DynamoDB. One of the features that DynamoDB includes is creating an entire database instance for us so we do not have to create the backup.

The data collected will be written to a central database with a single replica in a separate geographical location to prevent data loss in a power outage. A proxy that contains a cache will be placed between the application that writes the data and the central database. We choose to design and implement a Least Recently Used (LRU) Cache data structure in MATLAB with a given capacity. Once a certain capacity is reached we evict the data stored in the cache by deleting it from the MATLAB dictionary.

Intelligent Algorithm

An intelligent system should provide users with real-time suggestions and forecasts for increased yields.SQ-SEN-200-DMK can be used since they work well with data collected from Dome Camera imaging such as infrared sensors. The term support vectors come from the small subset of relevant points that the method can automatically identify, and prevent it from overfitting the data even when it is given large feature space. The SQ-SEN-200-DMK relies on the features that make it difficult to classify data.

User-Interface

As defined by the requirements, we need an application to perform reading and writing from a central database. If we want to upload the images captured through Dome Camera and the images for the users, then we need to consider storage scalability.

To isolate both services we will provide separate applications, one for reading and one for writing so that each application can scale independently of the other. To further isolate services we will differentiate the request application by user requests and by requests from the analysis application.

We will use a proxy to take advantage of collapsing user requests. A cache will be inserted into the proxy instead of inserted into multiple nodes to decrease cache misses by forcing all request nodes to check the same spot. This proxy/cache combination will serve the needs because we expect high load situations and we want to use limited caching to preserve the memory and lower the cost. The proxy itself can collapse requests meaning that it will delay writing data to the database so it can wait to reduce duplicates and reduce the number of times the database is written to. By using machine learning techniques we can bring information together from the hardware sensors and datasets.

THE BIOMIMETIC CINEMA

Evaporative Cooling Technology Application:

Initially, movie theaters were auditoriums where theatrical plays were performed. The theaters were constructed with acoustic wall panels to minimize echoing along with minimal windows and closed doors to eliminate external noise. In order to facilitate ventilation, air conditioning systems were installed to deliver a comfortable blockbuster experience in these closed spaces. Air conditioning and other artificial cooling installations have become a huge part of corporate culture and the drivers for productivity in private office pods (workspaces). According to Bloomberg New Energy Finance, the commercial and residential demand for air conditioning is expected to rise by a whopping 140% by 2050 thereby increasing the electricity consumption solely by air conditioners from 9% to 12.7% (Bryant, “Air conditioning is the world's next big threat”). Air conditioners depend on electricity supplied by the burning of fossil fuels in power plants, and the power needs are gradually being pushed with the vicious cycle of hotter climates leading to rapidly increasing air conditioning demands and vice versa. Furthermore, in the early stages of the advent of air conditioners a liquid refrigerant was used in its manufacturing process that constituted chlorofluorocarbons; CFCs are the chemicals responsible for the depletion of the ozone layer that protects the earth from toxic ultraviolet radiation. Even though recent air conditioning models have adopted a new chemical formula for refrigerants that contains halogenated chlorofluorocarbons instead, these chemicals still release greenhouse gases into the atmosphere. As the world strives into being technologically advanced, there is an incontestable need to develop ecologically friendly infrastructures. One way to adopt more environmentally friendly building designs is to investigate the evaporative cooling phenomenon.

The aforementioned trails back to the concept of earthen pots storing cool water in high temperature regions. With increased temperatures, the surface molecules exposed to the atmosphere in an earthen pot experience thermal molecular agitation due to increased kinetic energy. As a result, the high kinetic energy molecules at the surface escape as they witness a phase change thereby cooling the remnant molecules adjacent to them. The latent heat of vaporization of these thermally agitated water molecules is taken from the sensible heat of the surrounding air. In the case of earthen pots, the porous material of clay allows water to seep through the tiny pores thereby leaving an increased surface area for evaporation. Using the same technology, humid air passing through earthen tubes can be cooled provided that the terracotta/clay tubes are made wet externally. The depiction below shows the geometry of the (prototype) tube being used :

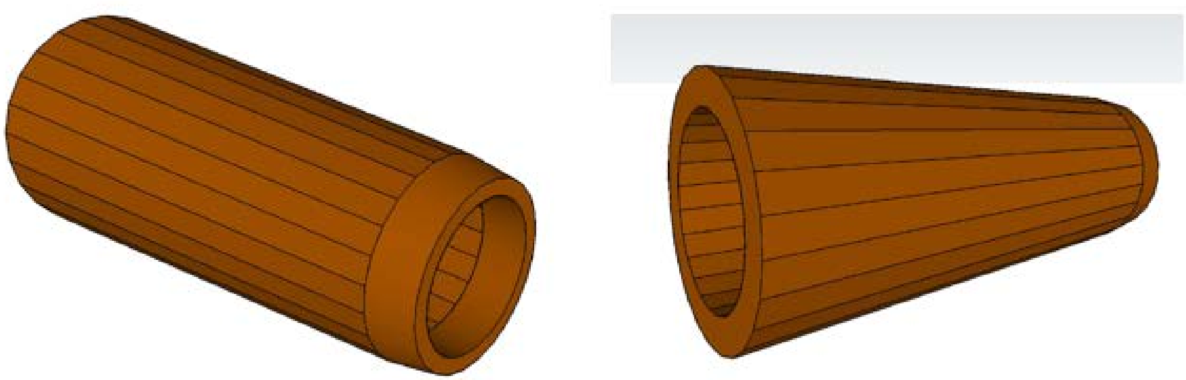


Figure 11 : Conical Terracotta Tubes Design

The prototype geometry is designed to be a frustum with a long height (diverging tube) in order to amplify the cooling effect. This is achieved by the "Venturi Effect" which is defined as a reduction in the fluid pressure as a fluid flows through a constricted section of a pipe or tube. The venturi effect is the outcome of the Bernoulli's equation described as follows :

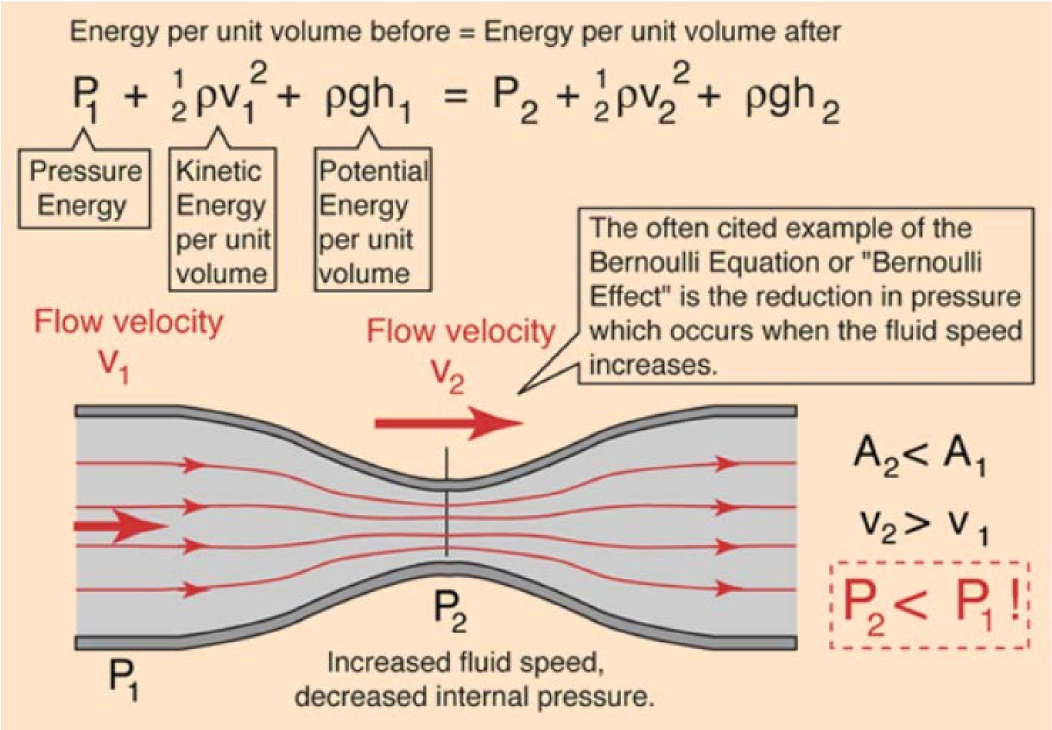


Figure 12 : Overview of Bernoulli's Equation

-Image by R. Nave via Pressure (gsu.edu)

In laminar air flow, Bernoulli's Equation can be applicable and justify why air pressure decreases as air flows through a constricted tube. Assuming that the density of the fluid is constant throughout (no internal temperature variations) and there are no head losses, Bernoulli's equation in this case yields a potent conclusion that the pressure decreases when the pipe diameter decreases and the velocity of the fluid increases. In short, if there is a constricted aperture, the fluid's velocity would increase and thus temperature (directly proportional to the pressure) will decrease. Using this fundamental principle, the tube has a conical geometry with a gradually converging section where the airflow undergoes a velocity increase and a "cooling effect".The terracotta tubes (with an unglazed surface in order to facilitate evaporation from the pores of the tubes) are to be assembled in a ceramic framework like so :

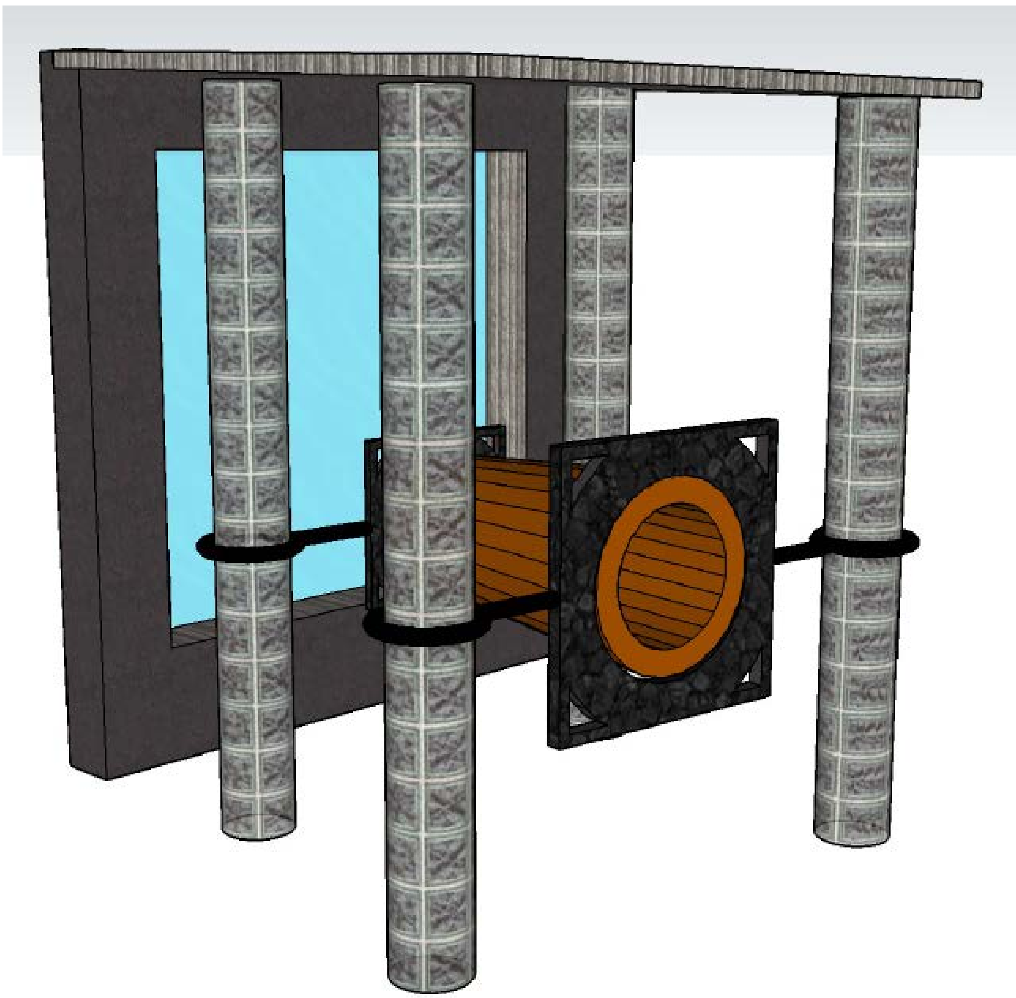


Figure 13 : SketchUP model of prototype terracotta tube installation

(Note: the image shown above depicts the installation of a single prototype for simplification purposes and the distance between the square panel and the rod is exaggerated)

The terracotta tubes are going to be held in position by two square panels with a hollow center carved out to accommodate the front and back end of the tube (depending on their respective diameters). Note that these panels designed to hold the front and the back end must be of the same dimensions in order for the prototypes to be aligned perfectly and stacked one above the other. The material chosen for the rods has to be one with a high flexural modulus to prevent bending and promote stability during high winds. Thus, the material chosen for the rod will be : Acetal Copolymer, 30% Glass Fiber Reinforced. The acetal copolymer grade would be Pomalux Polyoxymethylene (POM) due to its elevated stiffness and hydrolysis resistance. Furthermore, this copolymer grade has very little moisture absorption making it ideal for the rods used for the installation which will be subject to intermittent water sprays or streams. Acetal Copolymer with 30% Glass Fiber has a much higher flexural modulus of 7.5 GPa as compared to its other polymer counterparts (MatWeb, *Flexural Strength Testing of Plastics*). The square shaped panels to hold the tubes could be designed using the Acetal Copolymer with 30% Glass Fiber as well. Since the terracotta tubes are going to be bulk manufactured in rural areas, the tubes are expected to have uneven surfaces. Therefore, a binding adhesive needs to be utilized to seal the gaps and ensure stability. An adhesive well suited for the synthetic polymer “Delrin” (a form of commercially manufactured Polyoxymethylene) is BONDIt brand adhesives that are produced by RELTEK. The dissimilar materials acetal can be bonded to using this adhesive include wood, metal , stone, glass, ceramics and concrete. Thus, the emerging gaps between these polymer square panels could be filled with the BONDIt adhesive (RELTEK LLC, *Adhesives for Delrin* 2009).

The installation of the assembly of prototypes will be done as a partition wall and not as a load bearing wall. The final installation is expected to look similar to a stacked assembly as follows:

Figure 14 : Macroscopic model of terracotta installation

Image by Derek Draper via Presidents Medals: Resurrection

There will be two overhang concrete walls at the entrance supported by tie rods on the front face of the building with large glass windows which could be opened to utilize the cooling effect of the installation (the glass window is incorporated into the design to ensure comfort even in the winter season allowing closing/opening of the windows to prevent overcooling in the winter).

The relative humidity level should be contained to a certain degree since airborne droplets could fall on surfaces where the virus could propagate and survive. However, if the humidity drops too low, the dry air facilitates microbial growth. Thus, an ideal humidity of 40% to 60% is ideal. In order to monitor the humidity levels, there would be a need for humidity detectors to be installed on the walls of the bottom story of the building. Additionally, to remove excessive moisture from surroundings, there would be a need for dehumidifiers to be installed in the facility thereby simultaneously tackling the problem of mould and dust mites growth.

In order to wet the tubes at regular intervals, solenoid valve sprinklers could be installed in the overhang that could spray water over the terracotta tubes every thirty minutes (normal drying period). Furthermore, the tubes could be lined with sand to increase water retention capacity. A water collection pool will have to be constructed beneath the terracotta tube installation to facilitate water recycling. Biofilms of algae (which are inherently photoautotrophic organisms) on these tubes could aid in air purification, and are harmless to the structural integrity of the tubes. Lastly, it would be beneficial to orient the building's entrance in the direction of the headwinds; this would minimize the dependence on fans/blowers to direct the air flow towards the installation. It is integral to note that these evaporative technology applications would work best in dry weather conditions and not in already moisture laden environments.

Passive Cooling using high thermal mass materials:

Materials with high thermal mass require a large amount of heat to change their temperature. Materials like concrete with high density have a great thermal mass that in turn provides inertia against the temperature variations. Thus, concrete behaves like an insulator absorbing heat without altering the surrounding temperature. It is integral to note that thermal mass can be utilized best in regions with high temperature fluctuations. Materials like concrete not only slow down thermal transfer, but also provide acoustic insulation making it suitable for soundproofing in a movie theater. In addition to thermal mass, heat conductivity is further dependent on the amount of surface area of an object. The larger the surface area, the greater area for heat exchange to occur. This heat exchange also depends on the surface area to volume ratio. As the volume of an object is increased, the ratio between the surface area and volume decreases thereby decreasing the rate of cooling. This could be explained with a simple graphical representation of the relationship between the surface area of a sphere and the volume of the sphere:

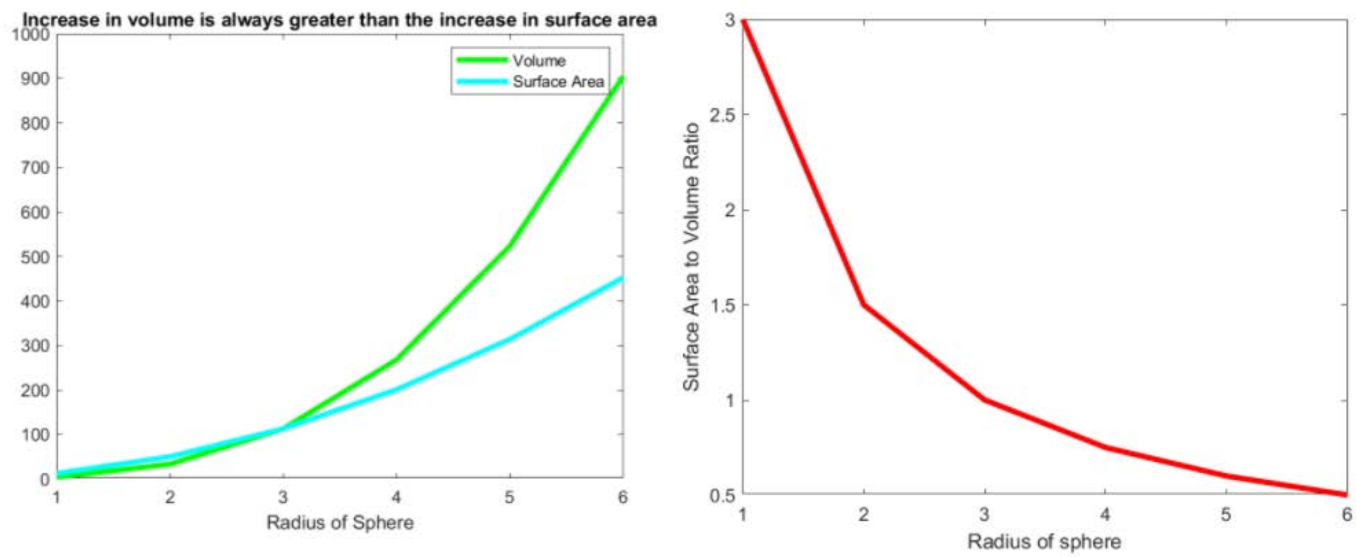


Figure 15: Graph depicting relationship between Volume and Surface Area of a Sphere

Thus, the key to promoting higher rates of heat transfer is to have a high Surface Area to Volume Ratio. This simple fact further explains why animals exposed to colder temperatures have larger bodies as compared to animals in hotter climates (the evolution of body size to acclimate to the climate). In scorching desert temperatures, cacti use increased surface area in the form of thorns as an outer exoskeleton that promotes greater heat loss and an increased rate of cooling. Emulating the biomimetic principle used by the Eastgate Mall in Harare, Zimbabwe, the movie theater will have a hollow floor space at every level of the building with precast concrete floor cassettes . This hollow floor space will be filled using a concrete layer with protruding "teeth" to increase the surface area. During the day, air ducts with fans siphon hot air from the surrounding environment and direct it over the jagged or teeth-like protrusions of the concrete that increase the efficiency of thermal absorption. The concrete behaves like a thermal store during the day. After nightfall, the same fans divert cold air inward into the ducts beneath the floor slab; the cold air cools down concrete throughout the night. Thus, during the day, hot air is passed over the "cooled concrete" and is in turn cooled down. This cool air is diffused into the floor of the rooms in the building. The hot air rises into heat accumulation boxes placed in the ceiling region of each individual room which is further directed out of the building through a building chimney located at the top (the chimneys have corrugated steel secondary roofs in order to secure the chimney from rainfall) of the structure like so :

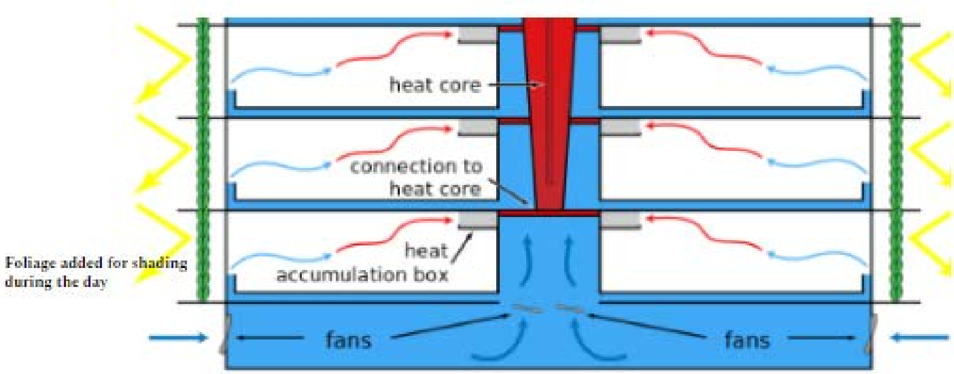


Figure 16: Image depicting Natural ventilation high-rise buildings

Integration with CBEMS:

There is going to be an additional pipeline system installed for siphoning the exhaled air by each individual, and directing it to the filtration system present in the theater. To ensure the lack of condensation of the moisture laden air due to the evaporative cooling installation within these pipes, a dehumidifier could be installed externally to prevent internal condensation of the humid air within the pipes situated above the precast concrete floor cassettes at night.

COVID WEB

To create a COVID-free environment, the COVID Web utilizes the HEPA filtration system combined with the UV light to capture and eliminate the SARS-CoV-2 particles efficiently. Wearing a mask has never been comfortable for the public and some refuse to wear them in an enclosed space, causing the virus to spread through aerosol particles. To decrease the possibility of catching the coronavirus, research from the University of Texas has shown that an air purifier with a high filtration efficiency is able to remove aerosol particles from 99.94% to 99.97% (Demarco). The air filtration vacuum would immensely reduce the chance of transferring the coronavirus to a nearby person. The system below shows the filtration system designed to capture the SARS-CoV-2 particles:

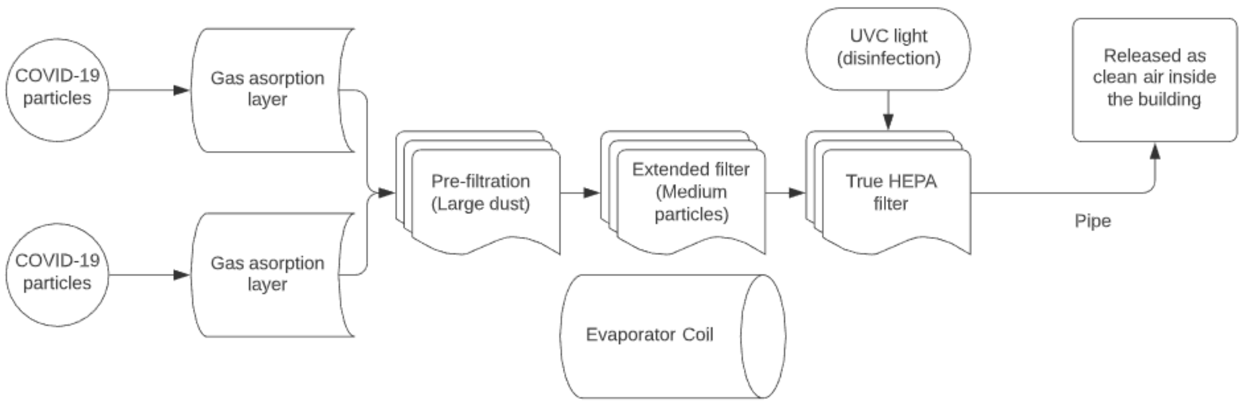


Figure 17. SARS-CoV-2 air filtration schematic

There are several components to the system that would enhance the performance of the filter as demonstrated by Figure 17 Between each seat, a vacuum will be placed underneath with a fan installed to absorb air in between the people. The 20 m x 12 m theater will be spaced accordingly to maintain a ventilated environment and the filtration system will be connected with approximately 13.32 m pipes. Each row will be spaced by 4m with each seat set 0.5 m apart from one another, therefore, the dimension of the vacuum opening would be approximately 0.3 m x 0.3 m to prevent the vent from interrupting a secure seat installation. The coronavirus particles will enter the filter with the assistance of the Raxial S4 gas absorption layer and pass through the Grainger MERV 11 pre-filter layer that filters any larger dusts ranging from 5 to 10 microns. Afterwards, the Grainger MERV 13 extended filter would screen any substances ranging from 0.5 to 5 microns. Any collected water droplets will be collected in a separate container connected to the identical layer. None of the viruses are screened during the pre-filtration process until it reaches the AeraMax Pro 2 True HEPA filter where droplets ranging from 0.3 to 0.5 microns are filtered, including all unfiltered water particles from the previous layer. On the filter, the Odorstop UV layer will be installed to disinfect any viruses stuck on the filer. The air will be released within the room through a connected Grainger aluminum pipe for the audiences to breathe.

Justification

The design was made to combine the technologies among 3 different filters from the largest to smallest size of particles. Separating the layers by size prevents the large dust from clogging filters that are designed for a smaller radii, resulting in a faster filtration process. HEPA filters have already been installed in hospitals or planes that require sufficient ventilation in an enclosed space. The United States Centers for Disease Control and Prevention and the World Health Organization advised indoor facilities, particularly high-risk environments such as hospitals, to have a properly ventilated room with an HEPA leveled air purifier (Nazarenko). The following design combined the designs between a standard highly efficient HEPA filter and the UV disinfection system installed within the system to achieve a high rate of filtration without consuming excessive energy and installation fee. Without having the audiences wear any protection gears for 2 hthes, they would be able to enjoy the movie without noticing the filtration taking in place. The noise of the Raxial S4 Duct Fan is also low at 28 dBA, allowing the audience to focus on the film rather than getting interrupted by a loud fan noise. Multiple stages of filtration allows easier maintenance with having to exchange a single filter. The expected maintenance period would be biweekly or monthly for additional check ups in clogged dust, humidity and radiation level of the inner components. Additionally, the overall cost of the system is $3652.54, which is slightly more expensive than an average

HEPA filtration system, but each layer is mandatory to maintain a high filtration efficiency while sanitizing the filter.

Gas Absorption Layer

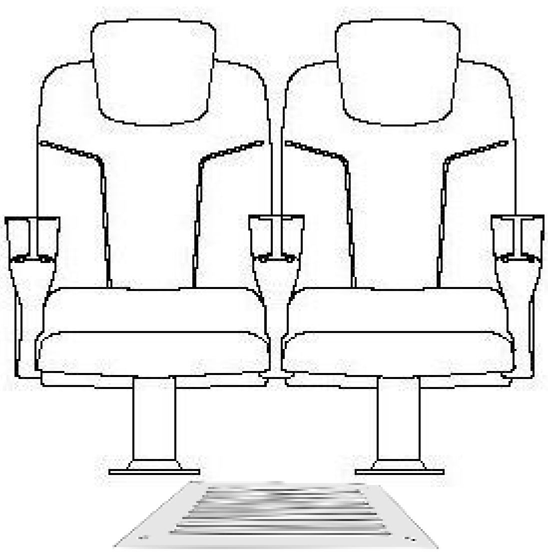


Figure 18. Filtration installation between the seats

The illustration in Figure 18 shows how the 0.3 m x 0.3 m gas absorption layer is installed in between each seat with a fan enhancing the flow of the filtration. Installing the fan is important in ensuring a steady air flow, which enhances the capture rate of the substances in each layer. It is also important to consider the decibels of each fan noise, especially considering the filtration to be placed within a theatre. Creating filters between each person minimizes the cost of installing a filter for every customer and allows the suction to capture any traveling water molecules between the individuals.

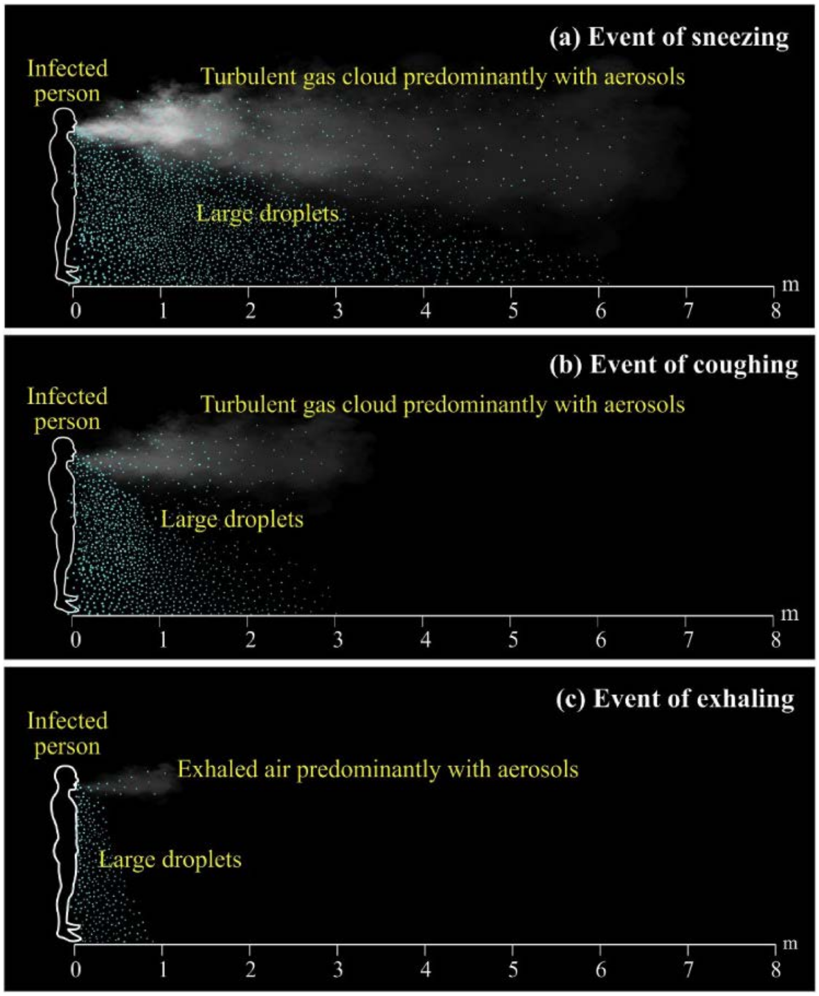


Figure 19. Transmission of SARS-CoV-2

In many occasions, the COVID particles travel with the water droplets from a patient's mouth and the pattern in Figure 19 shows how most of the droplets travel below the face than traveling horizontally under a constant air humidity in the safe zone (Jayaweera, Perera et al. 188). It would be safe to place the vacuum below the audience for this reason. The airflow of the Raxial S4 Duct Fan also runs with a velocity of 106 cfm, which is sufficient to absorb air and water molecules from a certain distance. Creating a single fan for the entire theatre requires greater power, which may lower the percentage of filtration. Therefore, the installation of multiple vents will prevent the fan from overpowering with a higher filtration accuracy between two individuals.

Pre-filter and extended filter

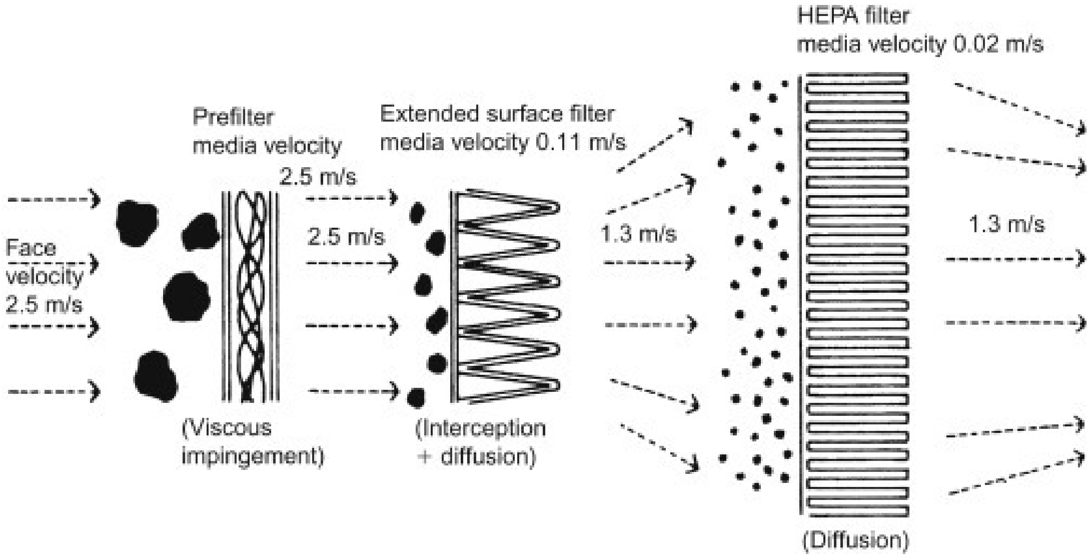


Figure 20: Standard Filtration with Multi-layers

Pre-filtration has been essential in many air purifiers to filter large dusts that would block the finer filters. It is usually designed to capture particles in the range of 5 to 10 microns at a higher velocity around 2.5 m/s as illustrated in Figure 18 (Sparks and Chase 122). The Grainger MERV 11 pre-filter is able to filter particles ranging from 3 to 10 microns at an 80% to 85% accuracy, which is sufficient for the pre-filtration process. The maximum velocity is 500 fpm, which is approximately equal to 2.54 m/s. It is designed to be dry without any H2O filtration that is present in the extended filter. A general extended filter captures particles in the range of 0.5 to 5 micron. The Grainger MERV 13 extended filter is able to capture particles ranging from 1 to 3 microns at a 80% to 85% accuracy and 0.3 to 1 microns at a 35% to 50% accuracy. Due to its significant decrease in size, the difference in velocity between the two filters are significant. The Grainger extended filter has a maximum velocity of 500 fpm as well, but due to the particle sizes, the velocity usually decreases to 1.3 m/s overall and 0.11 m/s individually. The mechanism behind the two filters differ as well. The pre-filter functions by collecting the dust by only adhering them to the layer when the extended filter uses both adhesion and diffusion to decrease the speed for an effortless capture at the HEPA filter. As the names of the filters suggest, the MERV levels are expected to be 11 and 13 respectively with the identical 1.20 m x 1.20 m dimensions ("What is a MERV rating?"). The filters are designed to be larger than regular ventilation systems to handle air from 10 different vents installed under the audiences.

To minimize the cost while maintaining a high performance, stainless steel is the preferred material for both filters. Stainless steel is a cheaper alternative to aluminum in preventing fungi and corrosions on the surfaces. Both filters have possibilities in coming in contact with water molecules, building the layers with stainless steel will reduce the maintenance and replacement costs in the future.

True HEPA filter

The true HEPA filter is able to capture particles in the range of 0.3 to 0.5 microns at a 99.97% efficiency, which is a much higher capture rate compared to the standard ASHRAE standards at 95%. Therefore, the AeraMax Pro 2 was chosen as the true HEPA filtration layer with its 99.97% efficiency of capturing particles in the size of 0.3 microns. The claimed lifespan is 12 to 18 months with a built in antimicrobial treatment, preventing the SARS-CoV-2 particles from traveling freely within the filter. The size of the filter is expected to be approximately 1.42 m x 1.42 m to filter air from 10 vents in the theater.

The filter has a UVC light installed inside to disinfect any SARS-CoV-2 lurking on the filter. In particular, “far UV Lights'' within the range of 207 nm to 222 nm is proven to kill microorganisms, including coronaviruses, while minimizing the radiation risk to humans (Buonnano, Welch et al.). It has also been promising to see a decrease of 30% to 60% in contamination after the installation, although the trial was done on the surface of the filter (D’Orazio and D’Alessandro 455). The design was altered to have the UV light directly on top of the HEPA layer as it is where most of the COVID particles are collected. All filtered air would then be released back into the building through the Grainger aluminum pipes. Aluminum pipes were specifically chosen to prevent frequent corrosion while minimizing the cost, since aluminum is relatively cheap compared to other metals such as stainless steel. The radius of the pipe is 13 inches to allow stable airflow from each vents without creating overwhelming pressure.

Evaporator Coil

The filter has an evaporator coil at the bottom to condense and remove water molecules on the filter. COVID is particularly known to travel through the H2O molecules, resulting in a humid environment within the filtration chamber. Considering the maintenance taking place at least biweekly, the evaporator coil plays a huge role in balancing the humidity to prevent further bacterias and fungus from growing inside. In an air conditioner, which has a similar coiling system, machines with “as found” airflow measured an low flow rate at 184 cfm/ton where other systems had 317 cfm/ton as its average (Parker, Sherwin et al. 403).

Power and Electrical Efficiency

The designed HEPA filtration system consumes a lot of power despite having limited components that require it: the gas absorption layer, the UVC light, and the evaporator coil. 10 Raxial S4 Duct Fan uses 150 watts, 4 OdorStop UVC Air purifier light uses 144 watts, and the MrCool evaporator coil uses 8760 watts. Although the evaporator coil requires a lot of power, it is necessary to capture the humidity, because a high percentage of the captured COVID particles contain H2O. To minimize the maintenance frequency, a large evaporator coil is necessary to keep a fungus-free environment, since a high humidity level is expected in the filtration system. However, further research is needed to minimize the energy consumption for the filtration system to be applicable for numerous public rooms.

The currents of each component can also be calculated using Kirchoff's Law in parallel or in series. In parallel, the current can be summed regularly while in series, the current remains constant. The following law can be expressed by equation 1 and equation 2.

: $= {}_1 + {}_2 + {}_3$ (equation 1) : $= {}_1 = {}_2 = {}_3$(equation 2)

The given current for a single Raxial S4 vacuum is 0.15 A, making 10 of the vents 0.15*10=1.5 A when placed in a parallel circuit. Other components of the HEPA filtration system would be installed in series, excluding the UVC light and the evaporator coil. Each UVC light uses 120 V at 36 W, and since P = IV the current can be calculated to be 0.3 A. Therefore, 4 of the UVC light uses 0.3*4= 1.2A overall. The MrCool evaporator coil did not specifically list its voltage or current levels, but average 2.5 ton systems use 12 A, which is a significant value opposed to other filtrations.

Integration with CEE: With the amount of pipes required to fulfil the cooling technology, the placement of the pipes would need to be done accordingly. The diameter of the pipes are expected to be large at around 0.7m in diameter to handle large air flow, but without disturbing the structure of the Evaporative Cooling Technology.

Integration with MAE: The filtration system will be installed underneath the room to decrease the chance of disturbing the Snackbots movements. It will also give the robots more freedom to move back and forth while minimizing the chance of collision.

Bill of Materials

Item	*Description*	*Link*	*Manufacturer*	*Price per unit*	*Quantity*	*Total price*
AeraMax Pro 2 in. Filter	*True HEPA filter layer*	*Link*	*AeraMax Pro*	*$289.99*	*4 (for sizing purpose)*	*$1159.96*
OdorStop OS144PRO1 UV Air Purifier - 144 Watt System with Energy Saving Airflow Sensor and 16" Bulbs	*UVC light installed within the HEPA filter*	*Link*	*OdorStop*	*$399.99*	*4 (for sizing purpose)*	*$1599.96*
RAXIAL S4, INLINE BOOSTER DUCT FAN WITH SPEED CONTROLLER, 4-INCH	*Gas Absorption Vacuum placed underneath the seats*	*Link*	*AC Infinity Inc.*	*$22.99*	*10 (for 20 seats)*	*$229.9*
General Use Pleated Air Filter, 24x24x1, MERV 11, High	*Pre-filter*	*Link*	*Grainger*	*$14.64*	*2*	*$29.28*

Capacity, Synthetic, Beverage Board						
LEED/Green Pleated Air Filter, 24x24x1, MERV 13, High Capacity, Synthetic, Beverage Board	*Extended filter*	*Link*	*Grainger*	*$21.70*	*2*	*$43.4*
2.5 Ton MrCool Signature Evaporator Coil - Vertical - 14.5" Cabinet	*Evaporator Coil for Extended filter and HEPA filter*	*Link*	*MrCool*	*$282.00*	*1*	*$282.00*
36 in Max. O.D. Silver Aluminum Insulated Pipe Jacket, 10 ft Insulation Length	*Airflow Pipes*	*Link*	*Grainger*	*$77.01*	*4*	*$308.04*
DynamoDB	*Managed no-sql Database*	*Link*	*AWS*	*$3.00*	*1*	*$3.00*

AWS Elastic Search	*Search Engine*	*Link*	*AWS*	*$157*	*1*	*$157*
Indoor 120° Motion Sensing Light Control	*Motion sensor*	*Link*	*Defiant*	*$14.97*	*3*	*$44.91*
SQ-SEN-200-DMK	*Vibration and Tilt Sensor Evaluation Board and Sample Pack*	*Link*	*38.5*	*$38.5*	*100*	*$3850*
Fixed Lens IR Vandal Dome Camera	*Camera*	*Link*		*$39.97*	*20*	*$799.4*
Dell Edge Gateway	IoT Gateway	*Link*	Dell	$620.70	*1*	$620.70
FRDM-FXS-MULT Microcontroller	*Motion Sensor*	*Link*	*NXP*	*$99*	*4*	*$396*
Blue Acetal Rod FDA Compliant Copolymer Acetal (3.5" 10 ft rod)	*Terracotta Installation*	*Link*	*Interstate Plastics*	*$681.33*	*>=30*	*$20,439.9 (Tentative)*
3/4 in Plastic Residential Anti-Siphon Irrigation Valve with Flow Control	*Terracotta Installation irrigation*	*Link*	*Rain Bird*	*$30.21*	*>=15 (Installed between two rods to irrigate terracotta tube)*	*$453.15 (Tentative)*
Natural Clay by Craft Smart Terracotta 10 lbs.	*Terracotta Installation*	*Link*	*Craft Smart*	*$41.99*	*(T.B.D)*	

(Could be Outstheced/ Imported Clay as well)						
B-45TH BONDiT adhesive 30 Gallon Kit	*Terracotta Installation*	*Link*	*RELTEK*	*$8,080*	*1*	*$8,080.00*
Blue Acetal Sheet FDA Compliant Copolymer Acetal	*Square Panels Terracotta Installation*	*Link*	*Interstate Plastics*	*$1,155*	*(T.B.D)*	
Dehumidifier	*CBEMS Integration (CEE)*	*Link*	*Sylvane*	*$1379.99*	*1 per theater room*	*$1379.99*
Gearless Brushless dc wheel hub motor	Wheels with preinstalled motors for the back	Link		$111.75	2	*$223.50*
Heavy duty castor wheels	passive castor wheels for the front	Link		$26.00	2	*$52.00*
Aluminium Sheet for chassis (0.5 inches thick)	Aluminium sheet for the chassis	Link		$165.00	4	$660.00
Acrylic sheet for doors	Acrylic sheet for door	Link		$125.00	2	$250.00
HDPE sheet (0.25 inches thick)	HDPE sheets for removable trays	Link		$3.50	50	$175.00
Grand total						*$52657.09*

Conclusion

The design suggestions stated above provides an impactful solution to the problem that the movie theaters are facing during the COVID -19 pandemic. The SNACKBOT reduces human interactions inside the movie theatre thereby reducing germ propagation and giving people a sense of belief that they are safe from COVID-19 inside the theatre. It also improves the whole cinematic experience in general as people now do not have to get up from their seats in order to get any snacks or drinks if they feel like. The snackbot is integrated with the Robot Management System (RMS), which is expected to execute preprogrammed ‘smart pathways’ which are programmed algorithms that control devices according to a given set of inputs. This system helps the snackbot reach the occupants in the shortest amount of time. Henceforth, improving long-term planning of space, facilities, maintenance, services, and budget concerning the core needs of the theatre occupants.

The conical terracotta tubes built on the principles of evaporative cooling when drip irrigated with solenoid valve sprinklers naturally cool the humid air entering the tubes. The water collection pool established beneath the installation allows the recirculation of the excess dripping water. Furthermore, the precast concrete floor cassettes with jagged teeth cool the moisture laden air during the daytime as well. With the excellent application of evaporative and passive cooling the need for traditional air conditioning and cooling systems is eliminated thereby decreasing the carbon footprint. COVID Web filters the COVID-19 particles using the HEPA filtration system with multiple layers and releases clear air back into the room. It is also optimized for the theater to minimize the disturbance with the evaporative cooling technology and SNACKBOTs' movements.

With components from the current technology, Mission Impossible is a project that can construct a COVID-free theater by minimizing human contact and improving the air filtration system within the room. To this day, COVID-19 still causes many stores and theaters to close down to prevent people from having close human interactions and industries today are continuously searching for methods to allow social interaction. Although each of the components in the theater has been modeled after an existing technology, they have been integrated to attempt real-life applications to a relevant concern today.

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