Virginia Tech War Memorial Hall: Integrative Team Design

Project Description

Architectural engineering students participating in their capstone course were tasked with designing the structural, mechanical, and electrical engineered systems for War Memorial Hall on the campus of Virginia Polytechnic Institute and State University, commonly, Virginia Tech, located in Blacksburg, Virginia.

The original structure, built in 1924, underwent reconstruction in 1972, leaving only the portion that serves as the building's façade and headhouse to the main campus quad, known as the drill field. The 1924 structure must be preserved in the new remodel, though teams all opted for complete demolition of the 1972 addition with a rebuild in its footprint.

Project Requirements

Incorporating integration, flexibility, and innovation, and given a budget of $45 million, the following design features were required to be included in the new War Memorial Hall addition:

- Remodel the 1972 addition or demolish and rebuild in its footprint
- Relocate at least 50% of the offices and classrooms in current headhouse to new addition
- Create a Wellness Hub in the 1924 War Memorial Hall headhouse to include
    - a Knowledge Commons;
    - a relaxation zone; and
    - a grab-and-go healthy snack bar.

Project Challenges

- increase the thermal performance of War Memorial Hall by 30%, specifically through improvements to the efficiency of the building's envelope;
- achieve natural ventilation for all regularly occupied spaces including classrooms and offices;
- increase spatial daylight autonomy to minimum 40% from the current 17%; and
- create a cohesive connection to legacy building.

Additional Design Goals

Virginia Tech's added design goals were that War Memorial Hall would demonstrate:

- **Heart of Campus**, a student destination for connection, collaboration, and a wellness community; War Memorial Hall will be the premier destination for the students at Virginia Tech to come together to connect, collaborate, and seek wellness as a com-munity.
- **efficiency** in cost, layout, and consumption;
- **stewardship** through sustainable design that considers community safety and minimizes energy consumption and carbon footprint; and
- **integration** to harmonize the unique character of a legacy building with modern technology to provide the best user experience

Over two semesters, students were immersed in a realistic design process resulting in a full packet of deliverables. Industry volunteers participated as team mentors or as evaluators for the deliverables and team presentations.

Collaboration of Faculty, Students, and Licensed Professional Engineers

The robust support system from faculty, licensed professional engineers and other industry mentors helped students collaborate to create and execute innovative and captivating designs. Faculty set up the requirements and checked milestones throughout the process in order to maintain continuous progress and provide learning opportunities. Faculty also guided students for effective presentations and professional communication with their mentors and within teams.

Industry professionals were partnered with student teams early in August 2019. A typical team of professional volunteers would include an architect, two electrical engineers, two lighting engineers, two structural engineers, and two mechanical engineers. Additionally, students could consult a code review specialist and an historic preservation expert.

Regular communication between students and professionals included, scheduled class time, weekly discipline design meetings at the professional's offices, and informal emails between in person discussions as guidance was needed. Mentors provided advice and information generally needed by inexperienced engineers, but PEs were often an excellent resource for specific aspects of the designs. For example, an electrical team, with one of their PE mentors, was able to observe a fully designed and functioning photovoltaic array and understand the requirements of photovoltaic monitoring before designing the PV and electrical systems for War Memorial Hall. Some teams had weekly face-to-face subdiscipline meetings with their mentors to review calculations and drawings and to ensure professional-level design quality. Ongoing dialogue with professionals helped identify and prevent problems early, brainstorm solutions, and verify their work as the design progressed.

Drawing from prior internship, coursework, and lab experiences, students also mentored one another throughout the project. Team members used the Clifton Strengths Test to guide them in selection for leadership and project management roles within the team. Leveraging technology and role diversity, problem solving and collaboration were carried out sometimes in parallel, and sometimes remotely, both synchronously and asynchronously. Students learned or honed software and design skills from working together and reported a more enriching and collegial experience due to co-learning from each other.

At each design process milestone, teams presented progress by discipline to simulate a professional setting. Presentations were evaluated by another set of volunteer professionals who graded the presentations according to a strict rubric and provided feedback on the student presentations and submitted documents. Follow-up questions and comments allowed students the opportunity to improve not only their designs, but also their professional communication skills needed to maximize the impact of feedback.

In total, 51 engineers, 6 EITs, 7 licensed architects, and 4 other professionals collectively volunteered over 6000 hours to these teams, ensuring the highest standards were met for the following team presentation deliverables:

- Collaboration Plan
- Architectural Design
- Past Projects Research
- Research
- Schematic Design (SD)
- Design Development 1 (DD1)
- Design Development 2 (DD2)
- Design Development 3 (DD3)
- Construction Documents (CD)

Through collaborative design, teams were able to:

- gracefully unite the architecture of the historic 1924 headhouse with the new construction;
- increase the percentage of occupied spaces receiving daylight to achieve spatial daylight autonomies (sDA) well above 40%;
- naturally ventilate all exterior class-rooms and offices;
- improve envelope energy performance by over 45%;
- meet LEED Silver Certification requirements;
- accommodate a student, staff, and faculty campus Wellness Hub;
- surpass client requirements for building mechanical, electrical, and structural systems; and
- achieve the client’s stated design goals.

Protection of Public Health, Safety and Welfare

The new Heart of Campus was designed from the beginning and throughout with health and wellness of people in mind, and safety and stewardship for the community as a whole. The new Wellness Hub in the 1924 headhouse invites everyone on campus to share a healthy and sustainable lifestyle. The LEED Silver level is met through sustainability in material reuse, energy metering, and use of renewable energies. Additionally, the energy consumed during construction and the environmental impact construction systems will have on the surrounding environment (e.g. runoff from concrete cleanout), was minimized. Systems and processes for use in construction of the new structure considered and minimized impact to campus life during the period of construction. Nearby suppliers were used in order to boost local economy while meeting LEED criteria reducing carbon emissions from transportation. The designed structure utilizes lightweight durable components to reduce the project cost while maintaining structural stability.

Safety of the occupants and the campus community are of the highest priority in every aspect of design, meeting and exceeding industry standards in every detail for fire protection, security, and emergency considerations. All these systems are backed up by the diesel generator emergency power systems designed by electrical teams. The building was classified as Risk Category III based on the number of occupants; this was a large factor in determining the appropriate building loads by structural teams. Mechanical teams followed appropriate design standards, but specific to protection of the public, health, safety and welfare, ASHRAE Standards 15, 55, 62.1, and 90.1 were all met.

Fire alarm systems were designed with smoke detectors, heat detectors, and notification devices connected to a control panel to route communication to the fire department via annunciator panels located at the main entrances of the building. Structural teams included a firewall between the 1924 headhouse and the new construction to prevent fire from spreading from one building to the other through the link and independently backed up the elevator on either side of the firewall by the generator be to provide accessible egress from either building section. Additionally, in accordance with state building codes, emergency lighting was designed to allow occupants to evacuate the building safely by illuminating paths of exit.

For security, an active shooter detection system was designed with detection devices located at the main entrances, in corridors, and in large gathering spaces to alert and direct authorities to gunfire locations. Other spaces like storage closets will be equipped with interior manually-operated flush bolt locks. A distributed antenna system was implemented into a design in order to amplify radio frequency signals within the building and allow for cellular networks to be accessible while inside of the building, adding an extra layer of security for the occupants.

Multidiscipline and/or Allied Profession Participation

Collaboration and professional mentorship inspired student teams to develop innovative design solutions from an integrated approach, maximizing efficiency by eliminating systems conflicts due to siloed subdiscipline design. Three student teams were made up of 2-3 mechanical-, 3-4 structural-, and 4 electrical engineering specialization students. A team of 6-8 engineers (structural, mechanical, and electrical) and 1-2 architects were assembled for each student team. Other specialists that were available for all student teams to consult with included a code specialist, a preservation expert and acoustics, fire and life safety, central plant systems, cyber security, and natatorium specialists as well as with faculty advisors in architectural engineering. In total, 68 non-faculty volunteers in all—51 PEs or SEs, 6 EIs, seven professional architects, and four other specialists acting as mentors or evaluators guided 30 students through their capstone experience. These collaborations result in student team designs that demonstrate an appreciation for the depth and breadth of considerations that are required to solve complex problems and the rigor required to complete a project.

Structural

Since all teams chose destruction and replacement of the 1972 addition, structural teams were tasked with designing the gravity, lateral, and foundation systems for the replacement structure in accordance with the 2015 Virginia Construction Code Students considered recommendations for materials such as steel, cold form steel, concrete, masonry, and wood construction and performed analysis for each structural system. War Memorial Hall was classified as Risk Category III based on occupancy—a major factor when designing for appropriate building loads. Using allowable stress design (ASD) ensured service loads would not exceed the elastic limit of members. Materials were then selected based on weight, time to construct, and over-all cost broken down by a per unit or per system basis for comparison and sourced by nearby suppliers to boost local economy and help meet LEED criteria by reducing carbon emissions due to transportation of materials. Designs used lightweight, durable components that reduced project costs while still ensuring structural stability.

Design of structural elements required an integrated approach to different mechanical and electrical systems within structural components to minimize floor vibration, improve visual aesthetics and functionality of those systems, design flexibility for system modification in future updates, and match the design aesthetics that are prevalent in the surrounding architecture, in part, by repurposing the Hokie stone from the demolition to blend new and historic architecture. Furthermore, the building's geometry, sloping site, and the existence of fill soils onsite (mostly clay and silt) presented unique challenges, requiring, for example, use of the basement and retaining walls in some areas for soil control. Additionally, the long spans above the pool (natatorium) and gymnasium spaces created challenges solved with integrative thinking for the, gravity, lateral, and foundation systems.

<u>Gravity system</u>

The gravity systems were designed to support applicable loads and transfer them to the foundation system. To provide a comfortable and serviceable system, deflection and vibration limitations were imposed on each the floor and the roof systems.

An example floor system consisted of a 2VLI19 metal deck with 4½" of normal weight concrete topping over composite steel wide flange beams. This system was designed as a composite, with the use of ¾" Ø shear studs welded to the top flange of the supporting steel beams. A maximum span distance of 8' - 0" was imposed to avoid overloading the deck. Slab reinforcement was designed to be 6x6W1.4x1.4 welded wire fabric.

A proposed roof system consisted of steel joists supported by wide flange girders with a 1.5B19 roof deck. Column design includes both HSS steel columns for the ability to hide them within walls and wide flange steel columns for the strength in a strong axis and ease of member connection.

Unique spaces such as the natatorium and gymnasium provided additional challenges and opportunities. For example, steel braced frames were used throughout the exterior of the building but additionally, precast concrete shear walls were used around the natatorium, providing not just the necessary increased support, but also mechanical insulation.

Lateral system

Steel brace frames were chosen for the main lateral load force resisting system due to their high efficiency and stiffness for a smaller overall building story drift. One team designed a single moment frame for the link space connecting the historic Head House to the reconstructed addition to allow for more freedom of movement within the high activity space. Since the connector link enables access to five different floor elevations between the 1924 structure and the addition, designs feature elements to avoid structural disruption of the original Head House. They incorporated structural stair stringers, for example, along with cantilevered shallow foundations. Expansion joints were designed by another team to handle maximum story drift and ensure the new structural system does not transfer any load into the existing 1924 Head House, structurally isolating one building from the other.

Foundation system

The foundations were designed to adequately and safely support the loads of the structure and transfer the loads to the soil below. Teams designed systems that consisted of shallow spread footings, retaining wall footings and helical piles, all with consideration for the data in the geotechnical report. While footings were designed for external checks like bearing and sliding using ASD loads, the concrete was designed and chosen using strength criteria.

Special systems

The varying topography called for large soil retention on two sides of the structure. Solutions for this included a cantilevered counterfort wall designed by considering data from the geotechnical report to retain over 25 feet of soil, effectively preventing any unbalanced earth pressure forces from being transferred to the steel lateral system. Footings along the existing 1924 Head House required additional attention in the interior of the building due to proximity between the existing and the new footings. One solution was to use a concrete pad supported by helical piles next to the Head House.

Another unique opportunity arose for the structural team to take an integrated approach to design members that span over 91 feet and support another story above that open space. Long span truss members were designed to carry the load of office spaces above the columns without compromising the open layout of the gymnasium below, while also mitigating vibration. A space truss solution allowed for a significant amount of daylighting through integrated skylights, and it was able to hide mechanical and electrical equipment.

Mechanical

Mechanical teams designed the HVAC, plumbing, and fire protection systems to be sustainable, preserve the historic legacy of the building, and promote the health of the occupants. Each team carefully considered initial cost, operating cost, maintenance requirements, reliability, quality of controls, and noise. Systems selections varied considerably across teams, but each solution was developed integrating innovative solutions to some of the stated design goals.

HVAC systems

For example, one team used three strategies to meet the client's request for natural ventilation: Foëhn wind capture, active green walls, and operable windows. Foëhn winds are strong, warm, dry winds that from the Appalachian foothills that can be supplied to most of the building. Active green walls are installed in high traffic areas to provide fresh oxygen and remove CO2. All teams provided operable windows all exterior offices and classrooms.

To achieve the goal of creating the "Heart of Campus" teams sought to maximize efficiency and create stewardship while ensuring a consistently comfortable thermal and air quality environment. Individual solutions were developed, featuring integrated designs such as a hybrid system with a geothermal loop, water source heat pumps, and water-cooled variable refrigerant flow. The geothermal loop uses the drill field as the main heating and cooling mode for War Memorial Hall gives the students pride in what the university is doing to advance the future and preserve the environment. The field provides a lowimpact energy medium to take and expel heat. At a macro scale, the condenser water loop serves as a heat recovery element that transfers heat to all connected elements of the building—the pool, gyms, offices, and classrooms. At a micro scale, a water-cooled variable refrigerant flow (VRF) system transfers heat when needed to similar spaces. Integrating these elements into the overall design reduced mechanical conditioning needs.

Aligning with Virginia Tech's 2047 master plan on best practices for campus, another mechanical element that increases stewardship is a plumbing design that includes a 13,000-gallon concrete cistern to service a rainwater harvesting system for system was designed for greywater harvesting to be utilized in hose bibs, urinals and toilets in the locker room, as well as irrigation for the drill field. Water treatment for the cistern is carried out through digital titration of the chlorine in the swimming pool. This not only reduces the need for clean water from civic systems, it saves the university approximately $23,035 per year, resulting in a 1.7-year simple payback.

Acoustics

Indoor noise criteria were developed for acoustically sensitive spaces from the 2019 ASHRAE Handbook – HVAC Applications. War Memorial Hall contains a variety of spaces with different acoustic needs. To improve the occupant experience, acoustical designs considered noise control, sound isolation, room acoustics, and sound masking to meet the individual needs throughout. The designs demonstrate a deep and broad consideration for the variety of occupant needs, and potential sources of acoustical discomfort.

The outdoor mechanical systems were designed to minimize noise transmission to the surrounding residence halls, while indoors, sound attenuators were placed at the intake and discharge of energy recovery ventilators and heat pumps to meet each room's recommended criteria. Vibration isolators were installed for mechanical equipment, pipes, and ducts, but the exclusion of traditional internal duct liners (per VT campus standards) inspired other methods for mitigating duct noise including closed-cell liners, double-wall ducts, and sound attenuators. Walls with high sound transmission class (STC) ratings were selected to reduce sound transmission from mechanical and exercise rooms into acoustically sensitive spaces. A sound-masking system including sound-isolating walls were used in office areas to increase speech privacy. To achieve the target STC ratings, wall assemblies with fiberglass insulation, multiple layers of gypsum board, and resilient channels were selected.

A wood floating floor for the gyms and rubber athletic flooring for the open exercise and weight rooms were chosen to provide impact isolation. To ensure speech intelligibility, a design even included sound-absorbing finishes to achieve the ideal reverberation time for each room. Acoustical ceiling tile, carpet, and wall panels were utilized in the classrooms, office spaces, meeting rooms, and collaboration areas. Acoustical treatments were also needed to reduce reverberation in the gymnasiums and natatorium due to their reflective surfaces and large volume. Wall panels and acoustical spray finish were selected for these spaces, as well as ceiling baffles in the natatorium.

A special note on attention to quality and detail, one team sought to confirm that duct-borne mechanical noise did not exceed noise criteria by conducting a duct noise analysis using Pottorff AIM. After researching the problem, the team determined that AIM uses outdated prediction models that may be inaccurate for duct liner attenuation. So, they built a custom script in Dynamo that predicts duct noise by automatically exporting duct parameters from Revit and applying methods used in the ASHRAE Handbook and tested to ensure acoustical criteria were achieved modeling maximum duct airflow velocities.

Electrical

Electrical teams designed the power distribution, lighting design, fire alarm and other special systems. All designs featured the 480/277 three-phase service provided from the campus utility service 2500 kVA pad-mount utility transformer. A 3000A switchboard was needed according to estimated lighting, mechanical, and appliance loads to serve as a centrally-located distribution panel. Backup diesel generator systems ranged from 200-400kW designs that provide power to required systems as well as optional standby branches. The backup system powers all egress lighting fixtures, the legally required standby powers, all emergency responder equipment such as fire pumps and smoke detection and control devices, while an optional standby branches power telecommunication loads and elevators.

A 75 kVA UPS system is in the main electrical room to serve all equipment located in IDF and MDF rooms in case of an emergency. Each electrical room includes a 480/277V panel for lighting loads, a step-down transformer, and a 208/120V panel for receptacle and other miscellaneous devices.

In an effort to decrease the carbon footprint as well as provide a potential cost savings for the client, photovoltaic systems were designed for the roof of the natatorium. Choosing a flat panel fixed system maximized the amount of power produced by the panels and Maximum Point Power Tracking (MPPT) was used to increase the efficiency of the panels and allow for individual monitoring and maintenance of each panel. Such PV systems will generate approximately 137,000 kWh per year, helping to offset the consumption of non-renewable energy by an already efficient mechanical system.

Lighting design

Lighting designers developed a concept statements to drive the design to meet Virginia Tech's goal. Examples of team concepts included, "Virginia Tech invents the future but doesn't forget the past," to preserve the legacy of the building and enhance the Collegiate Gothic architectural style while also creating a space to encourage future success; "Encompassing Brilliance," to motivate students and faculty to use War Memorial Hall as their center for physical and educational growth; and "Monumental Spirit," to draw and inspire students.

LED technology and a lighting controls system that complies with the 2015 Energy Conservation Code was integrated not only to reduce energy consumption but also to enhance the occupant's experience. Taking advantage of the daylight increases safety for occupants in the unlikely event of total blackout. Daylighting also increases the resiliency of energy systems and decreases the carbon footprint by reducing consumption due to electrical lighting. Using Sefaira, a SketchUp plug-in, the Spatial Daylight Autonomy (sDA) of the current design of War Memorial Hall was calculated to be 17%. By including vertical glazing and skylights in the design, teams increased sDA well over the 40% goal, with calculated sDA values ranging 43-48%.

Special Systems and Integration

The special systems in the building are the fire alarm, telecommunications, audiovisual, access control, security, and lightning protection systems. The fire alarm is integrated within the building's public address system with priority in an emergency, and was designed to seamlessly tie into the existing campus network. The fire alarm control panel (FACP) will be located in the telecommunications room TR closest to the fire department entrance with two remote FACP enunciators to comply with standards. Notification devices will include speakers, strobes, and speaker-strobe fixtures appropriate for location. A comprehensive wired data and voice system will be provided including independent pathways, telecommunication rooms (TR), equipment rooms (ER), and an entrance facility (EF).

TRs are located throughout the floor plan and have been stacked where possible. Minimizing adjacencies with rooms with plumbing fixtures and excessive electromagnetic interference factored into TR locations.

Cable between floors and through fire rated walls are protected by fire rated sleeves. The backbone cable for the data communications system is a 24-strand, 50-micron, multimode optical fiber. The copper backbone cable is a 25-pair CAT5e cable. The horizontal cable is CAT6a. Major pathways will be wire mesh cable tray in accessible areas with 20% extra capacity, and in inaccessible areas parallel runs of conduit with a spare empty conduit for expansion. Wireless access points will be fed by two Cat6a ports. When locating the wireless access points special consideration was used to account for high demand areas and obstructions, such as concrete walls.

Audiovisual systems have been designed for typical spaces. Classrooms and conference rooms were equipped with LED televisions, microphones for teleconferencing and remote-learning, and speakers placed in the ceilings for full coverage. Gymnasiums and the natatorium were outfitted with independent speaker systems and scoreboards. Open exercise areas, spin rooms, and other exercise spaces will be equipped with independent speaker systems and display televisions.

Security systems included restriction access control systems with card readers and video surveillance. The CCTV system, 360° cameras, will cover have an interior view of all exterior doors as well as hallway intersections and other entrances that require more security measures. Gunshot and active shooter detection systems were selected to be placed throughout and will be tied into the PA system and alarm systems. All power operators provided shall have auxiliary contacts for card reader and proximity reader functionality. In the instance of total power loss or fire alarm, all power-operated locks will automatically open in accordance with the 2015 Virginia Construction Code.

Knowledge and Skills Gained

Student participants gained and honed their skills and knowledge as a result of this immersive effort. Using a real-world building design project and having industry mentors prepared students well to begin professional practice with a clear understanding of the technical, personal, and intangible skills a competent engineer must develop and possess. It also reinforced the spirit of service professional engineers are expected to engage in, dedicating personal efforts for the community of engineers.

Technical Skills

Structural

- Software: Revit 2019, RAM Structural System, Tedds
- Timber Design
- Diaphragm Rigidity Analysis

Mechanical

- Software: Revit 2019, Trane Trace 700, Autocad 2019, Odeon 14
- Primary and Secondary System Calculations and Design
- Plumbing System Calculation and Design
- Acoustic Modeling

Electrical

- Software: Revit 2019, Navisworks, 3DS, SKM Powertools, Honeybee
- Power Distribution Design
- Lighting Design
- Special Systems Design

Essential Skills

- Communication
- Written, Verbal & Nonverbal
- Public Speaking
- Critical Thinking
- Interactive Design
- Problem Solving

- Leadership
- Conflict Resolution
- Delegation
- Teamwork
- Accept Feedback
- Team Building

- Working Collaboratively
- Work Ethic
- Punctuality
- Time management