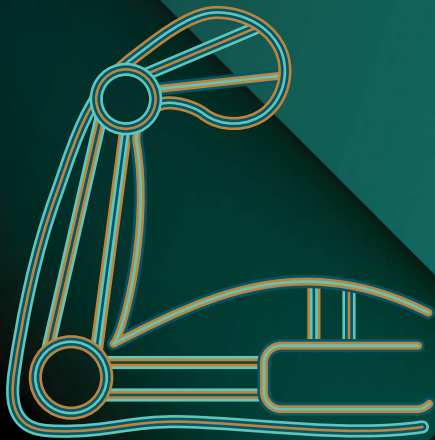




CENTER of  
EXCELLENCE

Research to Standards

EXO TECHNOLOGY



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ASTM INTERNATIONAL  
Exo Technology Center of Excellence

# ANNUAL REPORT

# Welcome

2023 was a year full of exciting educational events and activities within the ever-expanding exoskeleton community. This year, ASTM International's Exo Technology Center of Excellence (ET CoE) was able to connect with key stakeholders around the globe, share critical information, and forge new partnerships, including the robotics and automation communities.

The exoskeleton and robotics communities began the year celebrating the 10th anniversary of the NERVE Center at the University of Massachusetts Lowell. Major events in Texas, South Carolina, Washington, D.C., and Preston, England, took place throughout the year and are detailed in this report.

A keystone event this year was our inaugural Exo Games – a student-driven innovation initiative that simulated the challenges faced by engineers and scientists. The event exposed student teams to real-world applications of STEM, encouraging independent thinking and the application of a systematic approach to solve engineering requirements. The University of Central Lancashire, home to ASTM's Exoskeleton Student Chapter, hosted the event. You can learn more about the Exo Games, including information on all participating teams, in the following pages.

We know many of this year's accomplishments wouldn't be possible without our advisory board, ASTM's exoskeletons and exosuits committee (F48), and the

greater exoskeleton community. Volunteering their time to help assist, guide, and provide technical expertise to the center empowered our ability to help accelerate exoskeleton standards and educational efforts to the public, industry, and governments around the world.

The accomplishments you will find in this report reflect the ET CoE's objective of improving the quality of life and participation of all people through acceleration of exo technology research, standards, testing, and training. We hope you enjoy. //



**William "Bill" Billotte, Ph.D.**  
ET CoE Executive Director,  
ASTM International



**Katharine E. Morgan**  
President,  
ASTM International

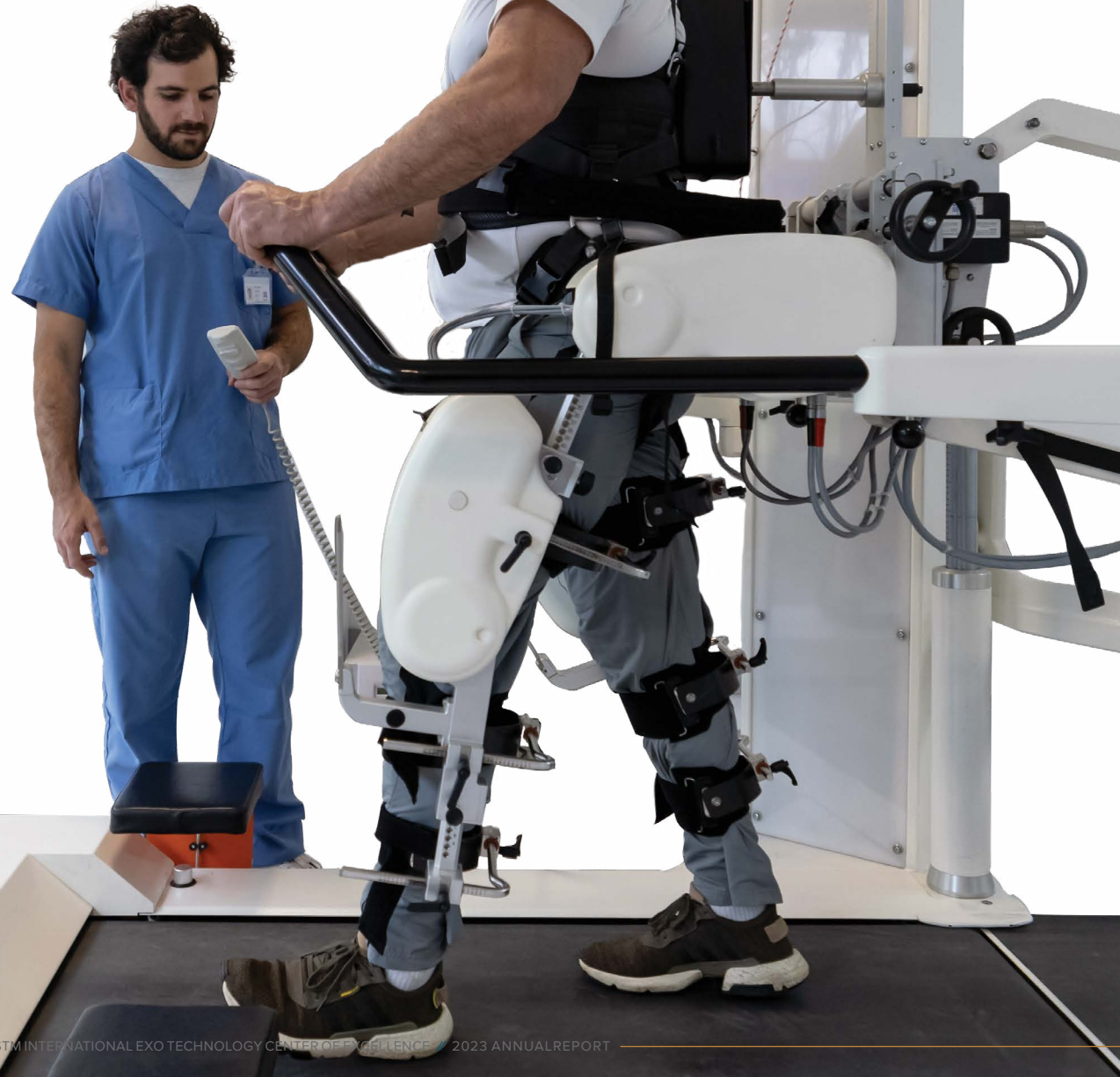


**William A. Eills,**  
Vice President of Sales,  
Vibram USA

# 02

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# Overview

For more than 125 years, ASTM has been at the forefront of standards development, enhancing industry performance and empowering consumer confidence around the world. We integrate consensus standards – developed with our international membership of volunteer technical experts – and innovative services to improve lives... Helping our world work better.

## OUR CORE VALUES



WE  WELCOME

WE  SERVE


WE  COLLABORATE

WE  INNOVATE


WE  BELIEVE

ASTM International's **Exo Technology Center of Excellence** (ET CoE) brings together industry, healthcare, academia, and government to address priority areas for the global exoskeleton community. Our vision is for people of all ages to be able to pursue a high-quality of life and fully participate in work and society thanks to safe and reliable exoskeletons. We accelerate research-to-standards, conformity testing and certification, and education and workforce development. The ET CoE prides itself on motivating and empowering the current and future generation of leaders along with sparking new connections to grow lasting global communities and initiatives.

## Our Goals

**BUILD TRUST AND CONFIDENCE** IN THE SAFETY OF EXO TECHNOLOGIES. 

**CREATE STRONG PARTNERSHIPS** ACROSS AND WITHIN DIFFERENT INDUSTRY SECTORS. 

**CREATE A KNOWLEDGE CENTER** THAT SERVES THE EXO COMMUNITY WITH TRAINING AND CERTIFICATION, TECHNICAL EXPERTISE, AND DATA. 

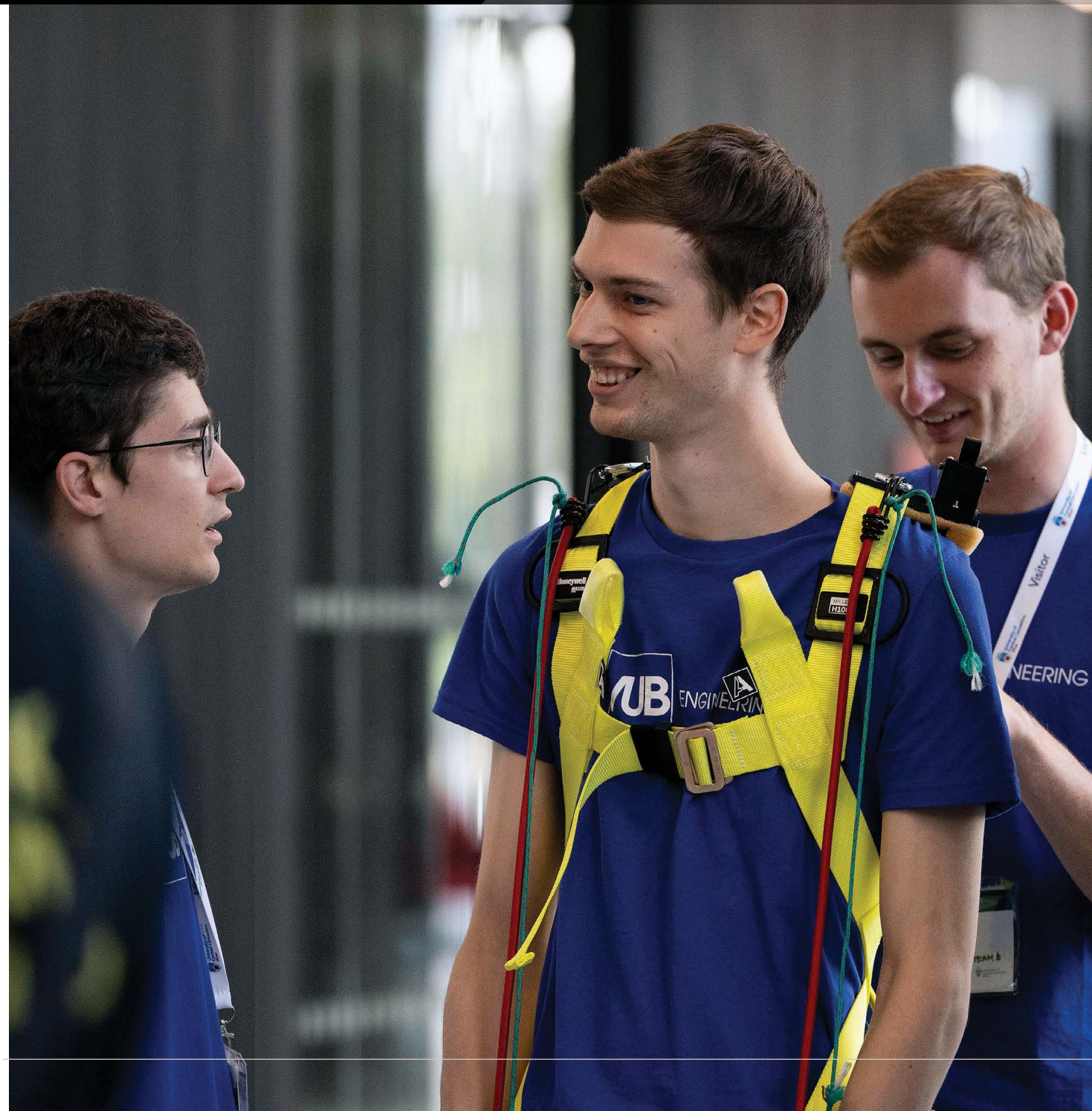


# 06

## PARTNERS & COLLABORATORS

# Partners & Collaborators

We collaborate to increase the ET CoE's technical, business, and communication capabilities to better serve the exoskeleton community. The ET CoE actively looks for collaborators that share our passion for exo technologies and seek to make a difference through service to the community.



## 2023 Partners

- New Stone Soup \*
- Exoskeleton Report LLC \*
- Prime performance LLC \*
- Human Factors and Ergonomics Society (HFES)
- National Safety Council (NSC)
- South Carolina Research Authority (SCRA)
- U.S. National Institute of Occupational Safety and Health (NIOSH)
- National Institute of Standards and Technology (NIST)
- Smart HLPR
- University of Michigan – Dearborn
- SwiftMotion
- Virginia Tech
- LiUNA TriFund
- Boston Engineering Corporation
- U.S. Army Combat Capabilities Development Command, Soldier Center (DEVCOM SC)
- Automotive Exoskeleton Group (AExG)

\* Founding Partner

# Research- To-Standards

We innovate by working with others to produce new knowledge and standards through directed research efforts on the highest priorities of the exo community. The ET CoE applies targeted funding and resources toward high priority research areas and cost shares (i.e., ratio of 1:1) the project with our collaborators. These efforts benefit our technical committees, exoskeleton producers, researchers, and provides opportunities for students to participate in impactful STEM activities.

The ET CoE's research activities result in draft standards, presentations, data, journal articles, reports, and are integrated into classroom lectures where appropriate.



## Completed Projects

THESE DRAFT STANDARDS ARE UNDER CONSIDERATION AND UNDERGOING VOTING VIA BALLOT.

### 1. Test Method Definition for Lower Extremity Exoskeleton Locomotion Transitions

University of Michigan

- WK76543 Standard Practice for Lower Extremity Exoskeleton Locomotion Transitions** – This Project was funded to develop a description of a set of artifacts used together in an obstacle course to enable evaluation of human-exoskeleton transitions and inclusive metrics of performance. This practice supports combining artifacts together to examine transitions between tasks.

### 2. Development and Standardization of Exoskeleton Test Methods for Mobility on Variable Terrains

University of Massachusetts, Lowell

- WK75742 Standard Test Method for Exoskeleton Use: Mobility Over Variable Terrains** – This Project was funded to develop a detailed test method for evaluating mobility of an exoskeleton wearer (i.e., locomotion, traversal) over variable terrains including characteristics of slope (e.g., flat, inline, decline), substrate (e.g., paneling, sand, gravel), elevation (e.g.,

stairs, raised cobblestones), and movement (e.g., forward walking, sidestepping, agile movement). The test methods are applicable to the evaluation of exoskeletons to determine if they improve and/or interfere with wearer mobility

### 3. Test Methods and Measures for Evaluating Cognitive Fit of Exoskeletons

Texas Tech University

- WK84201 Standard Guide for Assessment of Exoskeleton Users' Cognitive Performance** – This Project was funded to provide guidance on the methods that can be used to assess potential changes in the user's attentional performance associated with exoskeleton use. Changes in attentional performance may affect the user's task performance and could have potential implications for the user's safety and the cognitive fit of the system.

#### 4. Global Survey of Healthcare Professionals Using Medical Exoskeletons

The ET CoE surveyed healthcare professionals to gather foundational information on their use of medical exoskeletons in clinical practice. The survey aimed to understand their experience with medical exoskeletons, their perspectives, and their unique insights about using these devices for patient care. The learnings from this project can be used to improve exoskeleton technology and develop standards, education, and outreach programs to help drive the growth of the exoskeleton industry. More specifically:

- / Begin understanding the market landscape.
- / Design and produce better exoskeletons.
- / Identify key areas for further research.
- / Develop education, training, and certification programs.
- / Drive outreach, communication, and collaboration across medical professionals, researchers, and exoskeleton users.
- / Inform the development of standards by Committee F48 on Exoskeletons and Exosuits.
- / Put in place the necessary regulations to keep patients safe.
- / Catalyze the exoskeleton industry's growth and ensure that exoskeletons are genuinely helping people in novel ways.

#### Ongoing Projects

THE ET CoE AND ITS PARTNERS WORK DILIGENTLY TO IDENTIFY INDUSTRY NEEDS AND GAPS THAT THE CENTER CAN FILL BY FUNDING PROJECTS AND BOOSTING INNOVATION ADVANCEMENTS AROUND EXO TECHNOLOGIES. THE FOLLOWING PROJECTS ARE STILL COLLECTING DATA, ANALYZING RESULTS, AND/OR WRITING UP THE KNOWLEDGE PRODUCTS TO BE UTILIZED IN THE GLOBAL EXO COMMUNITY.

##### 1. Investigating Critical Challenges and Potential Solutions Towards Developing Standards to Guide the Proper Use of Exoskeleton for Injured Workers' Return to Work

University of Michigan – Dearborn

Investigating Critical Challenges and Potential Solutions Towards Developing Standards to Guide the Proper Use of Exoskeleton for injured Workers' Return to Work. Multimodal analysis approach along with advanced digital human modeling techniques and ergonomic analysis methods will be applied.

- / **WK65347** – Standard Guide for Utilization of Digital Human Modeling

##### 2. Development of Measurement Protocols for Efficient and Reliable Exoskeleton Testing and Evaluation

Virginia Tech

Determine the reliability and sensitivity of several objective and subjective outcome measures obtained when using either a back-support exoskeleton (BSE) or an arm-support exoskeleton (ASE) during different occupationally relevant tasks. Provide recommendations for study designs to reduce measurement errors and thereby improve measurement reliability.

- / **WK83361** – Standard Practice for Measurement Protocols for Efficient and Reliable Exoskeleton Testing and Evaluation

##### 3. Metrology for Emerging Technology, Robotics, and Exoskeletons (METRE) Intended for Industry and Public Safety

Collaboration Project with NIST

The goal of this effort is to develop a set of user-defined requirements in the application of exoskeletons within the domain of emergency response.

##### 4. Smart HLPUR

Based on priorities identified by the ASTM subcommittee on Task Performance and Environmental Considerations (F48.03) and the ET CoE Innovation and Research Team, Smart HLPUR is drafting the following standards based on a fully designed Roadmap of gap areas needing further standardization:

###### / **F3528** – Test method for exoskeleton use: gait

Gait is a component of many tasks that someone would do with an exoskeleton. This Standard Test method covers exoskeletons being used in industrial/occupational, military, response, medical, and recreational sectors to enhance safety and effectiveness of the user to perform tasks.

###### / **F3581** – Test method for exoskeleton use: hurdles

Hurdles are used in many tasks performed and may include, for example, upper, lower, or full body movement in order to complete the task. This test method addresses exoskeleton safety and performance requirements expressed by manufacturing, emergency responders, military, or other organizations requesting this test.

###### / **F3582** – Test method for exoskeleton use: gaps

Traversing gaps is a component of many tasks that someone would do with an exoskeleton. The safety and performance data from these tests are essential to guiding the procurement and deployment decisions of exoskeleton purchasers and users.

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## RESEARCH-TO-STANDARDS

Smart HLPR, continued

### / **F3584 – Test method for exoskeleton use: obstacle avoidance, walking**

Obstacles can vary greatly in, for example: length, width, height, quantity, geometry, and for a variety of industries (road construction, warehouse, manufacturing: floor/overhead, military, etc.). The testing results of the candidate exoskeleton(s) shall describe, in a statistically significant way, how reliably the exoskeleton user is able to avoid obstacles while walking.

### / **WK76431 – Test method for exoskeleton use: stairs (ballot stage)**

Being able to ascend/descend stairs, as intended by the user or test requestor, while using an exoskeleton is essential for exoskeleton deployment for a variety of tasks. This test method specifies test setup, procedure, and recording to standardize this stairs task for testing exoskeleton user movement.

### / **WK83509 – Test method for exoskeleton use: crawling (ballot stage)**

Being able to crawl, as intended by the user or test requestor, while using an exoskeleton can be essential for using exoskeletons in a variety of tasks (e.g., installing flooring, low-profile soldier movement, pipe installation in crawl spaces). This test method specifies test setup, procedure, and recording to standardize the crawling task for testing exoskeleton user movement.

### **5. NIOSH Longitudinal Study: Longitudinal Health Effects of Shoulder Exoskeletons in the Manufacturing Sector**

- A longitudinal design will be adopted to assess the health effects of existing passive shoulder exoskeleton users for repetitive overhead assembly work in a manufacturing setting. Aggregated injury and associated workers' compensation cost information will be collected over a two-year period. The Center serves as the data collector for study and will provide a mechanism to blind the NIOSH researchers to where the data originated.

### **6. Exo Technology Device Reporting Application**

- The ET CoE has developed a digital form which captures potential failure modes (i.e., incidents, near misses, and identified risks) in an anonymous manner that does not identify a particular brand of device. This information is utilized as input into future standards and research that will help the community identify common issues that need to be addressed. The data is voluntary and will be provided in an aggregated form to the F48 Exoskeletons and Exosuits committee and Center of Excellence staff.

The reporting form was launched in 2023 to F48 Members to test and ensure the robustness and usefulness of the Reporting Device. The Center plans on promulgating the availability of this Reporting Device to the global exoskeleton community in 2024





# 14

EDUCATION & WORKFORCE DEVELOPMENT

## Education & Workforce Development

### Buy America: Domestic Preferences for Exoskeleton Procurements

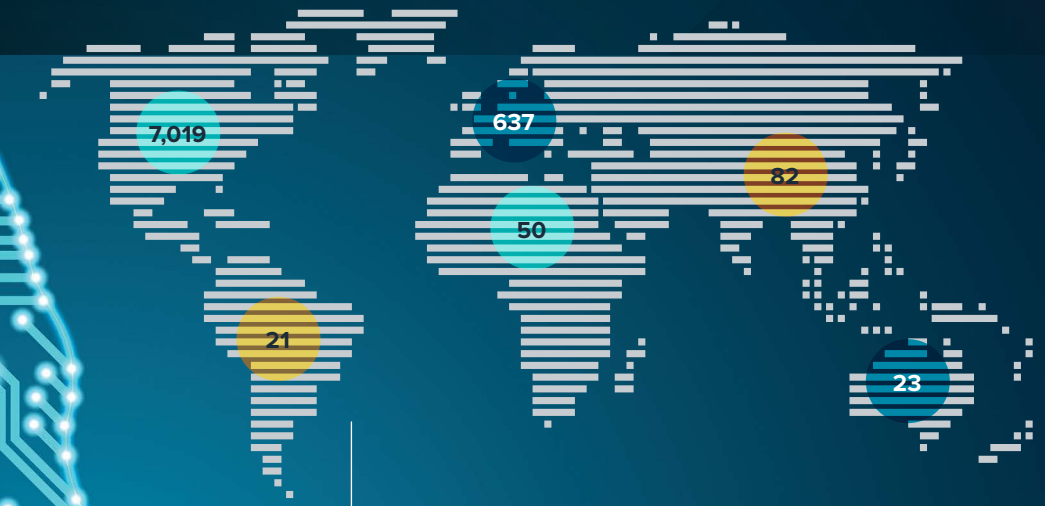
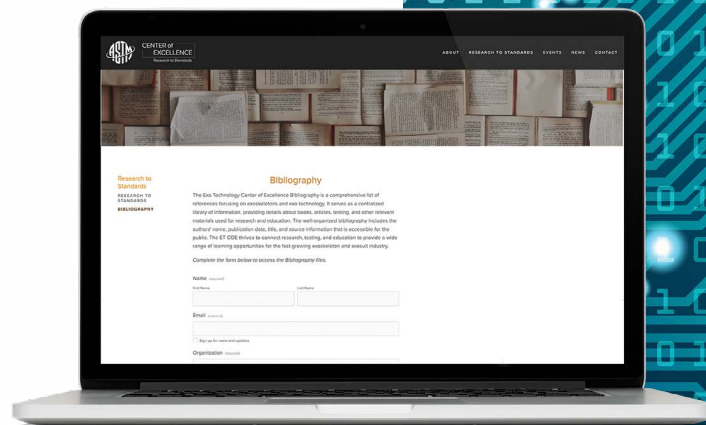
The ET CoE offered this free webinar to explain how sourcing and manufacturing components for a company could exclude it from potential customers. The webinar recognized guest speaker Paul Hurst from Steptoe, who explained the country-of-origin requirements applicable to federal procurements of exoskeletons.

### Bibliography

The ET CoE Bibliography is a comprehensive list of references focusing on exoskeletons and exo technology. It serves as a centralized library of information, providing details about books, articles, testing, and other relevant materials used for research and education. The well-organized bibliography includes the authors' name, publication date, title, and source information that is accessible for the public.

### Unleash the Bots

ET CoE and South Carolina Research Authority (SCRA) hosted an action-packed day where over 90 industry experts participated in an industry roundtable conversation to share common challenges and solutions within the manufacturing industry. Alongside the discussions, TECH Talks and demo technology solutions occurred from over 10 vendors that develop autonomous mobile robots, collaborative robots, and exoskeletons.



### Excellent Exo Chat – Listen Now!

Hosts, Bill Billotte and Nora Nimmerichter discuss exoskeletons, robotics, and emerging technology. With more than 70 podcast episodes now available, the podcast is used to increase the awareness of exo and emerging technologies in an informal manner. Guest speakers from industry, academia, and government have joined in the discussions to provide insight into the latest challenges and success of these technologies. The podcast passed 7500 downloads since its inception in March 2022.

### Newsletter

Issues of the ET CoE Newsletter were released in July and October last year to provide a snapshot of the efforts of the ET CoE, share updates from the exo community, and highlight Committee F48 on Exoskeletons and Exosuits work item registration and standards approved.



# Exo Games

## ASTM International Exo Games 2023

Since 2019, the ET CoE has been discussing and brainstorming an event unlike any other. An event that would bring together industry, academia, science, technology and bridge a connection between standards and the Exo world. From this, the idea of Exo Games was formed as the first-ever student initiative in the exo industry.



### 1st Place Overall

UNIVERSITY OF CENTRAL LANCASHIRE



### 2nd Place Overall

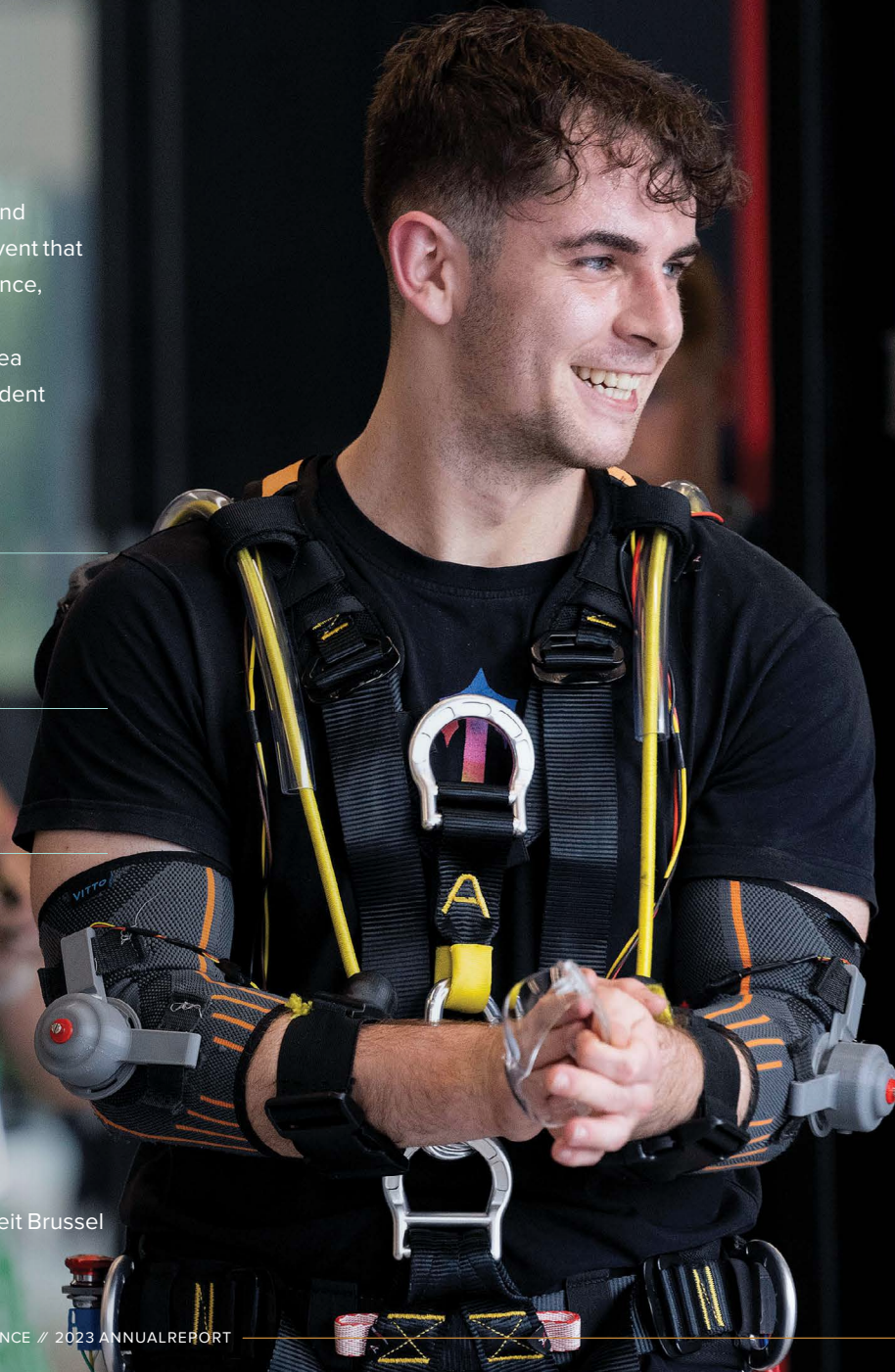
VRIJE UNIVERSITEIT BRUSSEL



### 3rd Place Overall

CLEMSON UNIVERSITY

- / **Teams' Choice Award:** Federal University of Technology - Parana and Pontificia Universidade Católica do Paraná
- / **Poster Competition Award:** University of Central Lancashire
- / **Presentation Competition Award:** Clemson University
- / **Design Competition Award:** Vrije Universiteit Brussel



The inaugural Exo Games, hosted at the University of Central Lancashire (UCLan), featured five university student teams from the United Kingdom, United States, Belgium, and Brazil. Teams competed in designing and constructing exoskeletons that met ASTM standards while also presenting their technical knowledge to an audience of over 60 attendees.

The three-day event was comprised of a Poster Competition, Presentation Competition, Main Challenge Competition, and Guest Presentations. The Main Competition included four physical tests. These tests — **Timed Up and Go (TUG)**, **Bomb Squad Walk**, **Warehouse Palletizing**, and **Cup Stacking** — evaluated aspects such as balance, repetitions, safety, and augmentation.

The student teams utilized over 15 ASTM International Standards to assist them

with their design, build, and participation in the Exo Games. The Exo Games offered an environment for learning without commercial concerns and provided a framework for collaboration. Industry experts and students were able to put international consensus-based standards into action and learn and innovate from the event. The Exo Games gave ASTM Members, industry, and academia early feedback that might otherwise have taken some time to discover.

Student Teams not only amazed attendees and judges with their designs, innovations, and performance but also their willingness to band together and provide each other with feedback and commemorative.



At this year's Exo Games, Hugh Herr (ET CoE AB Member) and Adam Gorlitsky (I GOT LEGS) shared their stories and inspiration with students and attendees. Hugh Herr's incredible speech on the new innovations

at MIT and Adam Gorlitsky's passion for an exoskeleton racing league left a lasting impression and sparked meaningful conversations among the future professionals of the industry.

**18**  
EVENTS &  
OUTREACH/  
ACCOMPLISHMENTS  
& METRICS

## Events & Outreach

### University of Central Lancashire Public Lecture

ET CoE representatives were guest speakers at, The Past, Present, and Future of Exoskeletons: A Public Lecture, hosted Dr. Matt Dickinson of the University of Central Lancashire (UCLan). The lecture featured discussions on the history of exoskeletons, and the innovative work taking place at UCLan.

### University of Massachusetts Lowell's NERVE Center, 10th Anniversary Event

ET CoE staff attended the 10th Anniversary of the University of Massachusetts Lowell's NERVE Center. The NERVE Center conducts research, testing, and evaluations across multiple domains and brings together people from various scientific disciplines and backgrounds to move the technology that powers our world forward. More than 100 people attended the anniversary event, which included demonstrations and a facility tour, to celebrate the milestone.

### Texas Public Safety Robotics Summit

In conjunction with National Institute of Standards and Technology (NIST), the ET CoE attended the Texas Public Safety Robotics Summit 2023 that showcased the use of robotics in a variety of environments

including in the air, in water and on the ground. The four days consisted of keynote presentations, live field demonstrations, training stations, and round

### State of Science Symposium Wearable Robotics

ET CoE staff attended the State of the Science Symposia Series: Wearable Robotics: Enhancing Performance, Reducing Injury, and Improving Rehabilitation. This symposium provided participants with an overview of the current state of wearable robotic technology and its clinical utility within the field of rehabilitation medicine.

### 2023 ErgoX Symposium

The ET CoE was a proud sponsor of the 67th International Annual Meeting of the HFES - Human Factors and Ergonomics Society and the 9th ErgoX Symposia. This year's event touched on the Future of Work theme and had invited keynote addresses by the Director of the National Institute of Occupational Safety & Health (NIOSH), Dr. John Howard at the opening of the event. His talk was titled "Emerging Technologies and the Future of Work". It also had a closing keynote address by senior scientist, Dr. Jennifer Cowley from the Chief Digital and Artificial Intelligence Office (CDAO) which reports to the Office of the Secretary of Defense. Her talk was titled "Accelerating the Adoption of Data, Analytics and AI for Decision Advantage".

**8** Advisory Board Members

**7** Completed R2S Projects

**15+** World-Class Partners

**10+** ET CoE Presentations and Outreach Events

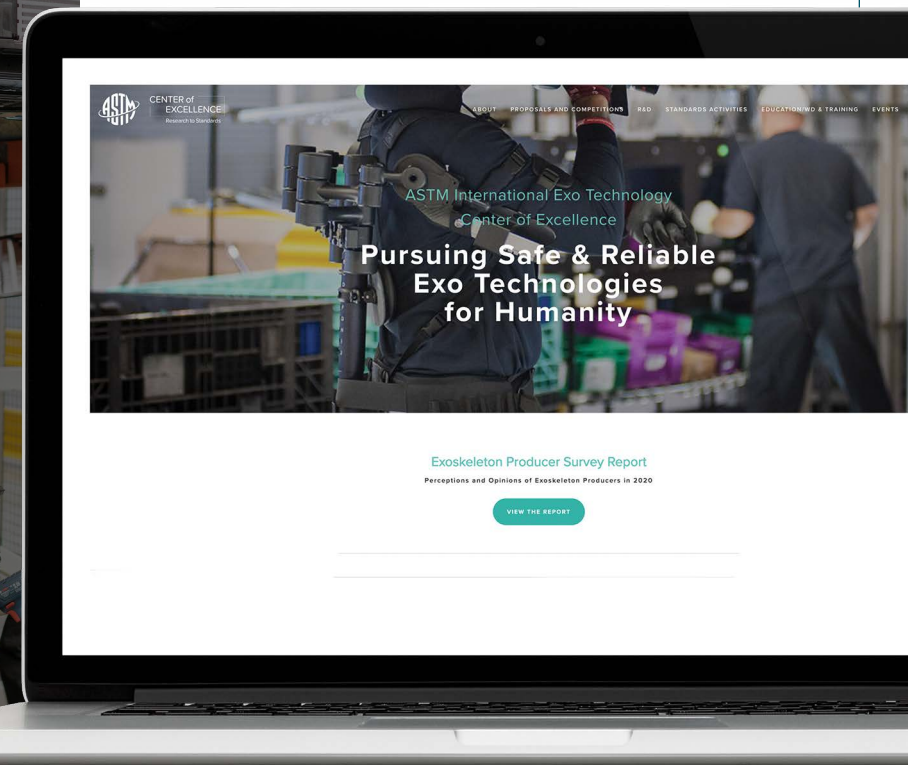
**5** R2S Projects

**8** Educational Events

**70+** Episodes  
**7,500+** Podcasts Downloaded

[www.linkedin.com/company/exo-technology-center-of-excellence/](https://www.linkedin.com/company/exo-technology-center-of-excellence/)

## Accomplishments & Metrics



# Leadership

## ADVISORY BOARD

The CoE's Advisory Board was chartered to provide vision and direction of the CoE to ensure that it remains current with the existing and future drivers of the exo technology industry. The current Advisory Board members are:



**David Audet**  
U.S. Army Combat Capabilities Development Command Soldier Center



**Hany Demian**  
U.S. Food and Drug Administration



**Hugh Herr, Ph.D.**  
Massachusetts Institute of Technology



**John Howard, MD, MPH, JD, LL.M, MBA**  
U.S. Department of Health and Human Services



**Philip Mattson**  
U.S. Department of Homeland Security



**Jim Miller**  
Sarcos Defense



**Samuel Reimer, Ph.D.**  
Ottobock Industrials



**Connor Walsh, Ph.D.**  
Harvard University



## CORE TEAM

A world-class ASTM International team oversees the daily operations of the ET CoE, facilitating coordination efforts among ASTM, various Standard Development Organizations, and stakeholders.

**William "Bill" Billotte, Ph.D.**  
ET CoE Executive Director

**Kim Brown**  
Senior Manager, Project Marketing and Strategy

**Natalie Hiller**  
ET CoE Intern

**Tessa Llewelyn**  
Program Manager, Business Development

**Brian Meincke**  
Vice President, Global Business Development & Innovation Strategy

**Len Morrissey**  
Director, Global Business Development & Strategy

**Nora Nimmerichter**  
Staff Manager and ET CoE Liason



Research to Standards

EXO TECHNOLOGY

## ASTM INTERNATIONAL Helping our world work better

Committed to serving global societal needs, ASTM International positively impacts public health and safety, consumer confidence, and overall quality of life. We integrate consensus standards – developed with our international membership of volunteer technical experts – and innovative services to improve lives...Helping our world work better.

### ASTM INTERNATIONAL HEADQUARTERS

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