BOARD # 320: An AI-Enhanced System to Integrate Unstructured Observations with Formal Engineering Education: An NSF RITEL Project

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Abstract

This article outlines the objectives, design, recent findings, and anticipated outcomes of a newly funded research initiative supported by the National Science Foundation (NSF). The project is part of the Research on Innovative Technologies for Enhanced Learning (RITEL) program, which prioritizes pioneering research in emerging teaching and learning technologies tailored to address critical challenges in real-world educational contexts. The primary aim of the project is to create, implement, and assess an AI-driven learning platform in the format of a mobile application called CeLens that acts as an on-demand educator to help construction engineering students learn from their unstructured observations during everyday activities. CeLens seamlessly merges students' observations during everyday experiences or formal site visits with their formal engineering education. The platform, designed based on the activity learning theory and developed based on human-centered principles, leverages advanced hybrid image-audio processing techniques to accurately and efficiently identify and explain diverse construction elements.

Introduction

The construction industry in the United States is one of the most significant contributors to the country's economy and employs over 8 million professionals.[1]. Like many other sectors, the construction industry is undergoing a significant transformation, driven by the adoption of new technologies that promise to revolutionize construction practices. It is essential for construction engineering students to become familiar with both traditional and emerging construction methods while gaining exposure to real-world construction tasks and engineering processes [2]. Traditionally, this has been achieved through organized construction site visits. While these visits offer valuable learning experiences, they are often constrained by safety concerns, limited availability, and time restrictions [3]. Furthermore, large group visits may prevent all students from engaging fully, as some may miss opportunities to ask questions or interact with experts due to factors such as limited access to professionals and individual traits like shyness [4]. Although construction site visits remain a crucial part of construction engineering education, opportunities to observe real-world construction are not confined to formal visits. Students living in urban areas often encounter various construction activities in their day-to-day lives, such as while commuting to school. Figure 1 shows several examples of active construction sites located within half a mile of one of the universities participating in this project.

Construction activities observed in students' daily environments, along with formal site visits through coursework or internships, offer valuable opportunities to witness real-world construction processes. However, without expert guidance, students may struggle to derive meaningful learning from these observations. We hypothesize that if educators were physically present to guide students by highlighting key construction components and interpreting their observations, these informal experiences could greatly enhance students' learning and integration of knowledge. Unfortunately, this level of direct, real-time expert support is impractical in real-world scenarios. To address this limitation, we propose an AI-driven solution that provides students with real-time expert guidance, enabling them to integrate insights from these contextual experiences into their formal education. In essence, the AI would function as an on-demand educator for construction engineering. Specifically, the primary objective of this project is to design, develop, and evaluate an AI-powered learning platform that uses an innovative hybrid image-audio signal processing system to help students learn from their informal observations and link them to their related course materials.

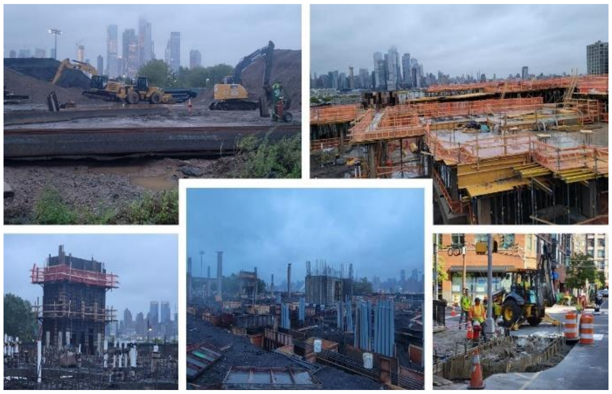

Figure 1: Examples of construction projects visible from public areas

Proposed Intervention

The proposed learning system, named CeLens (Construction Engineering Lens), will be implemented as a mobile application (Figure 2). Developed with a human-centered approach, the CeLens platform utilizes hybrid image-audio processing capabilities via students' smartphones. This innovative system is designed to identify and classify construction components into four main categories: (1) structural elements, including various types of foundations, beams, columns, and slabs; (2) construction materials, such as concrete, steel, and wood; (3) construction equipment and machinery, ranging from heavy equipment like excavators, bulldozers, and graders to hand tools such as rotary hammers, power dispensers, and grinders; and (4) construction operations, including tasks such as excavation, concrete forming, scaffolding, and steel erection.

Once CeLens identifies the primary construction components, it highlights them on the smartphone screen. To enhance student engagement, the platform first prompts students to identify the detected components by answering a multiple-choice question displayed on the screen. After students submit their answers, the platform labels the components accordingly. Students can then interact with these labels by tapping on them to access online construction libraries. These libraries are hosted on a cloud-based database and provide detailed information about construction components, organized into hierarchical categories for easy navigation and learning.

Figure 2: CeLens application

The proposed AI-driven solution combines pedagogical and technological innovations to enhance learning. The pedagogical innovation is designed to assist students in making sense of their unstructured observations of construction activities and integrating these insights into their formal engineering education. This is achieved by: (1) guiding students' attention to key construction components encountered in daily life or during formal site visits, (2) providing explanations for these observations, (3) connecting observations to relevant formal engineering education materials available through web-based learning management systems, and (4) generating automated reports on students' observations and performance to help instructors tailor course activities for improved learning outcomes.

The technological innovation driving the proposed pedagogical approach is a novel hybrid image-audio processing system, capable of efficiently and accurately recognizing and classifying various construction components. The integration of image and audio signals is crucial for detecting construction operations, particularly those involving heavy equipment. For example, audio is a more reliable signal for assessing whether a hydraulic hammer is active or idle, as the equipment may not move significantly but produces a strong sound. In addition to the hybrid processing method, this project aims to introduce two key advancements in audio processing and sound recognition: (1) the ability to operate using a single sensor, specifically a smartphone, and (2) the capability to capture audio data from distances of up to 100 feet. These technological advancements will enable users to analyze construction elements from a safe distance, and in many cases, from outside the construction site.

Research design

The AI-driven intervention proposed in this project is grounded in Activity Learning Theory, which provides a framework for analyzing human activities by focusing on the interplay between human actions and consciousness, particularly in an engineering context. This is crucial for designing effective learning environments [5-6]. The theory aligns closely with the project's goal of integrating students' informal observations of construction activities into their formal engineering education through the CeLens platform. In this framework, the "subject" refers to construction engineering students and instructors, while the "object" is the integration of unstructured observations into formal learning. The interaction between students and the AI-powered platform is governed by certain rules, and the "community" consists of students and instructors. A clear division of labor exists between students, the AI system, and instructors. The "production" aspect focuses on transformative learning experiences, specifically the successful incorporation of observational data into students' education. Tools, both physical and mental, play a pivotal role in shaping this learning process and influencing outcomes. These tools include smartphones, the CeLens platform, construction components, construction libraries, and course materials. The CeLens platform serves as a key mediator, influencing how students perceive and engage with construction components. It facilitates the integration of informal observations into formal education by guiding student interaction with construction elements. This tool-based learning approach influences activities such as recognizing, naming, and learning from these observations. Additionally, the comprehensive reports generated by CeLens impact instructors' actions, allowing them to adjust course activities based on students' insights and ensuring alignment with learning objectives. The platform's role as a transformative tool echoes the concept of tool mediation in activity theory, underscoring its influence on students' learning activities in the construction engineering domain. This reciprocal relationship between consciousness and activity aligns with the project's aim of connecting students' observations with formal learning materials.

The core technological innovation in this project centers on a novel hybrid image-audio signal processing system. The CeLens platform is designed to capture two primary types of data from construction sites: visual and audio. Visual data will be generated by all four construction component types—structural elements, construction materials, construction equipment, and construction operations. In addition, construction equipment and operations will produce distinct audio data. By employing a hybrid approach to process both image and audio data, the CeLens platform will be able to detect and classify construction components. While image and video-based object detection is a well-established research area, the integration of audio as a complementary data source is innovative and expected to significantly enhance the accuracy and efficiency of component detection. This combination of audio and visual data is particularly vital for recognizing construction operations, as existing computer vision-based methods often struggle to identify operations where equipment movements are minimal. For example, during the operation of a hydraulic rock breaker, its hammer moves only slightly, but the associated audio data is crucial for detection.

In addition to this hybrid approach, the project introduces two major technological advancements in audio processing and sound recognition: 1) Traditional methods rely on multiple microphones and complex microphone arrays placed at different locations around construction sites. Our approach eliminates this requirement, allowing students to record sound patterns using a single smartphone. 2) Previously, microphones were required to be placed close to sound sources, typically within 10-20 feet. In contrast, this project will extend the audio sensing range up to 100 feet, enabling students to capture relevant audio data from a safe distance, which is particularly important during both everyday activities and formal site visits where safety may prevent close proximity to construction equipment. To promote equity and accessibility in education, the mobile app will be designed to operate on the most basic and affordable smartphones and will use color palettes compatible with the needs of users with color vision deficiency (CVD), along with subtitles and audio narrations.

Progress and Results

This 36-month research project commenced in September 2024. Currently, the research team is focused on two key activities, both closely aligned with pedagogical and technological innovations. The first activity involves designing the CeLens mobile application based on human-centered design principles. A preliminary prototype of the application has been developed, and the team is now planning to engage users to finalize the platform's design. The second activity centers on preparing image and audio libraries of construction components to support the development of the image/audio analysis system. This task has recently been completed, and the team is now ready to begin developing the construction component recognition methods.

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