AC 2011-806: COMPLEX ENGINEERING SYSTEM LEANING THROUGH STUDY OF ENGINEERING CASES USING 3D ANIMATIONS

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Complex Engineering System Learning through Study of Engineering Failure Cases using 3D Animations

Abstract: Complex engineering systems often require dynamic coordination of multidisciplinary teams with conflicting objectives. Failing to understand the complex relationships among the conflicting objectives may result in serious engineering failures. In engineering education, one of the challenges in teaching complex systems is the lack of effective tools to demonstrate system dynamics, especially spatial-temporal relationships in the system. The described project in this paper is supported by grants from Engineering Education program of the National Science Foundation. In the project civil/construction engineering cases are used as the context to test the proposed new teaching/learning tool on the subject and to demonstrate the effectiveness of the developed tool. In building system design, structural designs mainly focus on the behavior of structures under design loads specified for operating stage. Typically less attention is given to the dynamic transient load during various construction stages. The insufficient considerations of the construction related transient loads may reach the critical point during construction and cause structural failure. For example, there were cases of bridge collapse during construction due to inadequate considerations of the load dynamics during construction. Also, many factors affecting construction transient loads were not technical. Rather, they are management related such as construction sequence and cost considerations. Thus, enabling construction students to learn from the similar cases through effective media is critical to avoid repeating the mistakes.

Based on the case-based and problem-based learning theory, the authors explored using 3D computer simulation of failure cases to help construction engineering and management students to develop a better understand of the dynamics between design and construction. In this study, a case about a high-rise residential building was used. The building collapsed due to many factors, such as improper construction sequence, poor selection of staging area, bad weather, and lack of shoring of foundation wall. Through this case, computer simulation illustrated the interactions of elements of different systems, including building, nature and the social-economic system, and how and why the interactions eventually led to a failure. To better understand the complexity of construction systems, information that was presented by the simulation was organized based on the structure-behavior-function (SBF) theory. In addition, this paper also discussed the technology used in the case study and simulation and the application of such simulation in construction education. The assessment method is to compare the learning results between the control student groups and the experimental student groups, on SBF concepts on complex engineering systems.

In summary, this paper presents the research background, a case study, research methodology, and 3D cases animations as a potential solution to address the existing problem - the lack of effective teaching tool to effectively teach context-rich case-based engineering cases. Since this is an ongoing research project, the final results of the hypothesis tests are not available yet.

Introduction

Multidisciplinary collaborations, uncertainty, and conflicting requirements are common in modern engineering systems as the domains for engineering applications continue to rapidly expand. A growing concern with current engineering education is the disconnection between the science-based engineering curriculum and current industry practices. In a typical engineering class, subject and theories are taught without much application context. In a typical real-world engineering project, complex constraints from the application context often requires solutions from compromise and prioritization of multiple engineering and non-engineering factors. "Many of the students who make it to graduation enter the workforce ill equipped for the complex interactions, across many disciplines, of real-world engineered systems" [1]. A report by the National Academy of Engineering [2] pointed out that a critical component needed for engineering curricula is to foster an understanding of the interrelationships between engineered, technical, and nontechnical systems. A study by Jonassen et al. [3] shed some light on what is lacking in conventional engineering teaching and learning. While real engineering problems are dynamic, most problems discussed in classrooms are well-structured, where parameters of the problems are specified in the problem statement. Often such problems "possess knowable, correct solutions that are achieved by applying preferred solution methods; and they apply a limited number of regular rules and principles that are organized in a predictive and prescriptive arrangement" [4]. Studies [5] [6] have pointed out that the knowledge required to solve well-structured problems is not readily applicable to solving complex, ill-structured problems in the real world. In addition, empirical evidence has shown that there is a difference between experts and students in solving complex problems [7] [8]. Hmelo-Silver and Pfeffer [8] found that novices tended to focus more on static components of a system, while experts applied an integrated approach of structures, behaviors, and functions to solving a problem. Consequently, it is critical to have a teaching and learning environment that enhances students' ability to solve complex, real-world problems in engineering.

The disconnections between industry practice and classroom curriculum calls for changes in engineering education from isolated and specialized programs to integral collaborative programs with input from multiple disciplines. One of the potential improvements to the traditional subject-based teaching-learning is to introduce problem based teaching –learning [9]. Using real-world engineering problems to challenge student, and through this problem-solving process to integrate the knowledge pieces acquired in different subjects.

In the context of civil/construction engineering, the transformation of the traditional civil engineering education is more imperative since the civil engineers as a profession are facing many challenges. According to the Vision for Civil Engineers in 2025 [10], dramatic changes to civil engineering practice are needed in order to answer emerging challenges. This will requires civil engineers to acquire not only extended technical skills but also nontechnical knowledge in actual professional practices.

Modern buildings consist of complex engineering systems [11], such as architectural, structural, mechanical, plumbing and electrical systems. These systems are often designed and constructed in a short period of time by many engineering and contracting teams from different disciplines or locations and with different interests.

What makes construction engineering even more challenging is that using a prototype to reduce risks and refine the design and construction is not an option due to the one-off and capital-intensive nature of building. This poses a great cognitive challenge for building professionals and students alike. Spatial-temporal cognition of building systems and their construction processes is at the center of many complex engineering and management issues.

Previous studies show that spatial-temporal cognition, a significant engineering skill in many disciplines, is largely determined by an engineer's ability to visualize objects and their evolving processes [12] [13]. Spatial complexity is related to the space arrangements of various building systems and components, as well as the cognitive effort of construction professionals to understand and mentally visualize such arrangements. On the other hand, construction is also about temporal process - sequences of construction activities. The temporal complexity arises from uncertainties associated with the execution sequence of a construction project.

Due to the dynamic coupling of the spatial and temporal structure, it is often difficult for students to fully comprehend the implications of a design and its impact on the construction. Consequently, costly design errors and misinterpretations of design documents due to the lack of spatial-temporal coordination become a frequent issue in construction projects. A case study is presented in this paper to illustrate the importance of understanding the complex spatial-temporal coupling of design and construction, for professionals and students alike. Enhancing students' spatial-temporal cognition will help students to conduct comprehensive evaluations of project risks, potential delays, rework and claims [14]. Therefore, for civil, building, and construction engineering students, spatial-temporal cognition is a vital component in developing correct concepts on many important engineering and managerial topics, such as site logistics, cost estimating, constructability, safety, project layout, and productivity.

It has long been recognized that students have difficulties in understanding and explaining complex phenomena meaningfully, such as emergence, self-organization, and stochastic processes [15] [16]. Notably, Jacobson and Wilensky [17] found that students need to go through a process of "strong" conceptual change in order to appreciate thinking in terms of complex systems. To achieve this conceptual change, they need to experience complex systems phenomena, develop a salient and explicit conceptual framework about complex systems, and actively learn concepts about complex systems. In addition, Hmelo-Silver and Pfeffer [8], Liu et al. [18], and Liu and Hmelo-Siler [19] proposed the use of a structure-behavior-function (SBF) framework for learning complex systems.

Whereas these studies provided a fertile foundation from which to draw theories and principles for pedagogic design, there are still many barriers that prevent the demonstrated theories and principles from being adopted by construction engineering and project management education programs. Two such barriers are of interest to the proposed research. First, experiencing the real world does not necessarily directly lead to the observation and appreciation of complex phenomena [17]. Thus, it is yet to be determined how spatial and temporal complexity should be presented to students in construction engineering and project management. Second, an explicit conceptual framework of spatial and temporal complexity in construction engineering and project management still needs to be developed and effectively integrated into the curricula.

Research goal and objectives

The authors are motivated by existing research findings in case-based learning or reasoning (CBL/CBR), computer technologies, learning complex systems, and conceptual changes [20] [21]. These findings provide an opportunity to construct a different pedagogical approach for teaching and learning construction engineering and project management. Computer technologies have been applied extensively in undergraduate education, such as simulations that emulate different types of complex engineering processes [22]. These applications have different foci. For example, Jacobson [23] found that a problem-based pedagogical environment involving cases was particularly promising in supporting conceptual changes. Liu and Hmelo-Silver [19] presented two experiments that demonstrated the use of hypermedia to promote understanding of complex systems by engaging students in learning functions and behaviors. Besides those applications in learning complex systems, computer technologies are used to simulate field trips [24] [25] and in problem-based learning [26], among other applications. In addition, visualization plays a key role in the human cognition system [27]. Studies [28] [29] indicated visual modes of representation are essential to the generation and dissemination of new knowledge in science and technology. Thus, a simulation-based environment that visualizes real-world cases may provide a promising solution, in lieu of real field trips, for students to experience the complexity in construction fields.

Simulation and visualization alone may not be sufficient to lead observable characteristics of complex systems. Dorst and Vermaas [30] provide a theoretic foundation to structure cases that are presented in the environment using structure-behavior-function (SBF) framework. However, an SBF framework needs to be instantiated in the context of this research. In construction engineering and project management, “structures” refer to physical structures, such as buildings, bridges or highways, stakeholders that are involved in the construction process of the physical structures, resources, and external elements, such as social, economic and natural systems. Thus, from a systems perspective, a construction project is multidimensional, including many subsystems at different levels. “Function” refers to the purposes of structures. “Behavior” refers to the mechanism of a structure to realize its function. For example, one of the functions of a retaining wall is to resist the movement of soil; and its behavior is that under design force the wall will remain at a standstill. Focusing on behaviors and functions will reveal hidden interactions between system elements, which represent a major cognitive challenge for students to appreciate the spatial and temporal complexity in construction engineering.

Contemporary studies on education have shown that the acquisition of new knowledge should be conceptualized as a transformation of prior knowledge [31]. A simulation and visualization environment with cases structured according to SBF may lead to such a transformation, i.e., cases are purposefully arranged to facilitate conceptual change. Although there isn’t a singular theory on the mechanism of conceptual change [32], Gentner et al. [33] found that conceptual changes resulted from contrasting and comparing different cases. This finding was in alignment with a previous idea, cognitive dissonance [34].

Although conflicts between a learner’s existing concepts and new phenomena alone may not directly lead to a conceptual change [35], techniques have been proposed to foster conceptual change. For example, Brown and Clement [36] proposed a method to use a connected sequence of “bridging” analogies. Zietsman and Clement [37] proposed the use of “extreme cases” to foster conceptual change. More recently, Jacobson [23] proposed problem-based learning (PBL) with cases to facilitate knowledge transfer and conceptual change.

According to the aforementioned theories and findings, it is quite plausible to develop a pedagogical tool to foster complex systems thinking skills of students in construction engineering and project management. The conceptual framework of the tool will include the application of computer-based multidimensional simulation of context-rich cases for students to experience complex phenomena in construction engineering and project management, an explicit conceptual representation of selected spatial and temporal complex phenomena that can be used to guide and evaluate students' learning, and a set of purposefully designed cases related to the selected spatial and temporal phenomena to trigger and ground conceptual change of students.

This proposed tool is called the Case-based Multidimensional Virtual Environment (CMVE) in this research. An overarching question of this research is whether CMVE can overcome barriers to trigger a conceptual change in students from structure-oriented thinking about complex systems in construction engineering and project management to function- and/or behavior-oriented thinking. Enhancing students' ability to handle complex problems is a crucial step in preparing future engineers to master a boarder spectrum of technical and nontechnical skills and compete globally. Thus, this research, if successful, may lead to a massive curriculum change that incorporates teaching and learning meta-cognitive skills related to dealing with complex issues in construction engineering and project management.

Framework of case-based multidimensional virtual environment (CMVE)

CMVE is purposefully designed for students to learn a set of core concepts related to complex systems in the context of construction engineering and project management and to develop skills to apply the core concepts in construction engineering planning and design. These core concepts include system and subsystems (or autonomous agents), nonlinearity, causality, emergence, self-organization, hierarchical levels, and so on [7]. The conceptual framework of CMVE is shown in Figure 1. Conceptually, CMVE has two parts which serve different purposes: Modular Cases and Learning Scaffolding.

Modular Cases: Modular cases allow students to experience spatial and temporal complexity through multidimensional simulation, i.e., using 2D/3D simulation, animation, video/audio, and regular text to reveal events, associated engineering principles, and technical, economic and natural constraints. This part features a function-oriented hypermedia design to reinforce function and behavior-centered thinking of complex systems, an in-depth analysis to reveal spatial and temporal complexity, and what-if scenarios to ground students' conceptual understanding about complexity.

The case presented in this paper was a failed high-rise building in Shanghai, China, shown in Figure 2. It recently collapsed due to poor understanding of spatial and temporal complexity. This case will be used to illustrate how students experience spatial and temporal complexity in CMVE, as described in the following paragraphs.

From an engineering education point of view, it is a typical example of the lack of understanding of the dynamic and stochastic nature of interactions among elements of complex systems (in this case, it is the interactions among construction cost, construction schedule, soil mechanics, foundation systems, and weather). Such understanding is critical in many construction projects. Currently, however, the separation between building design and construction often leads to static thinking about dynamic interacting systems during construction, which can create many problems. Typically, an engineer will not be responsible for how projects are built, which is the responsibility of contractors. However, there are complex interactions between the design boundary conditions and how a building is built. If contractors or engineers fail to understand such interactions, as shown in this case, failure will occur.

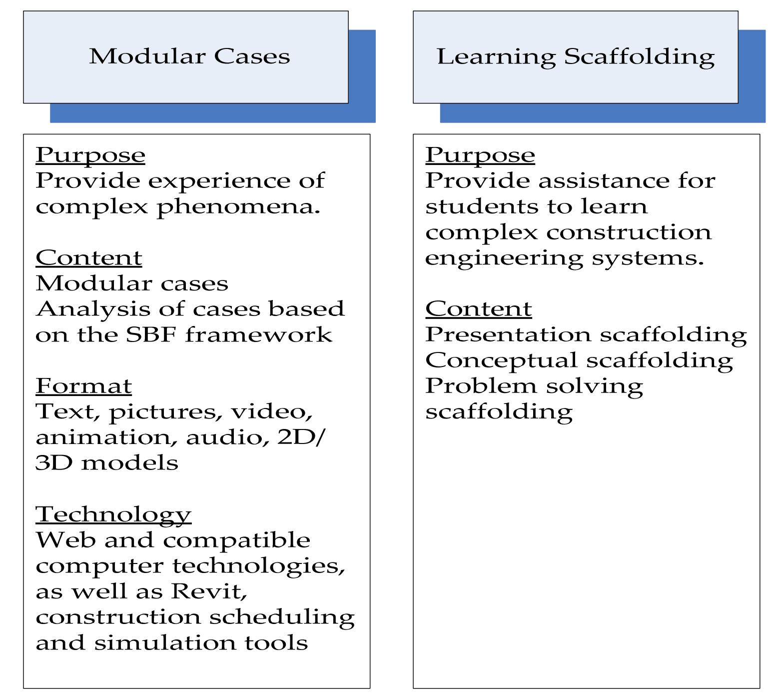
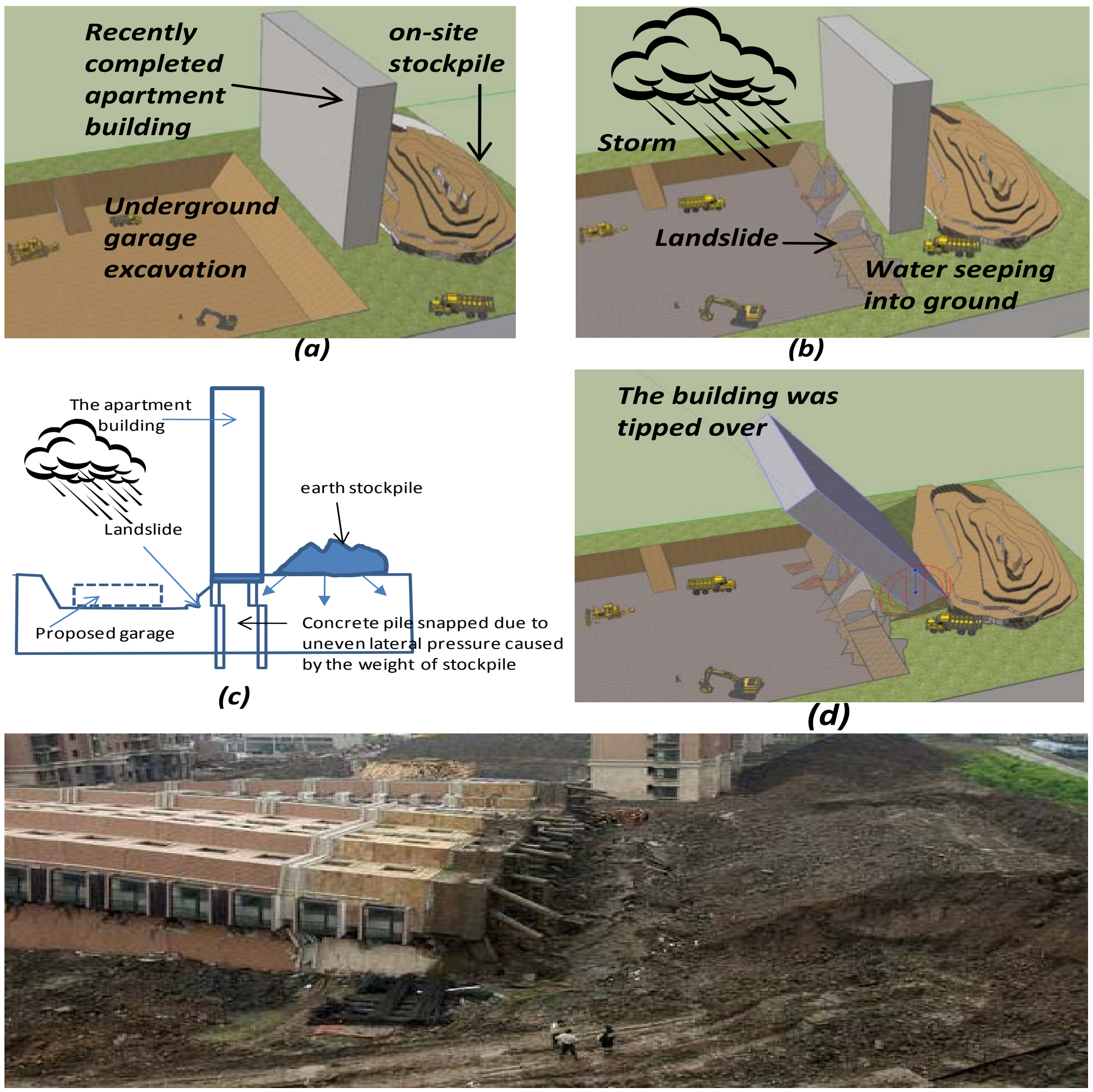


Figure 1. The theoretical framework of CMVE.

In the Shanghai case, the engineer designed the garage and the apartment building as one project. But the engineer did not have knowledge about how the contractor was going to build it.

First, the engineer did not know, when he/she designed the project, how the contractor phased the construction: build the high-rise apartment first and the underground garage afterward (for contractors it may be a quick and economical way to build the project). Second, the engineer did not know that the contractor would put the dug-out soil on the other side of the building and stockpile the soil 10 meters high. Third, the engineer did not consider that a heavy rain could come right when the building had stockpiled soil on one side and an excavation pit on the other side. The soaked soil lost friction which, combined with the 10-meter high earth pile, caused lateral soil movement and snapped the concrete foundation piles, tipping over the whole building (Figure 2 a, b, c, d and e).

This example clearly illustrates the need for construction engineers to understand the dynamic nature of the interacting elements from a complex systems point of view. However, current construction engineering and project management education lacks a synthesized tool to teach students the complex interactions among multiple engineering systems.



(e) Actual site photo after the accident

Figure 2. A building collapsed due to poor understanding of spatial and temporal and complexity.

Functional-Oriented Hypermedia Design: After the background of the case is given, the case will be structured and presented using the idea of Function-oriented hypermedia [19]. For example, Table 1 lists some elements involved in the cause of the collapse and is organized in terms of SBF. Then, a systems perspective of the case will be presented. For example, Figure 3 presents a systematic look at the event involving at least three different types of systems: building, nature (earth and storm), and the social-economic system (contractor). Hypermedia used to present the system will focus on function and behavior of structures (see Figure 4). Figures 3 and 4 are only intended to conceptually illustrate the design of case presentations. They are not necessarily the actual format that the authors will use to present cases.

Table 1. SBF Examples of Cases

Structure	**Behavior**	**Function**
Building	Maintain safety and integrity under tolerable external factors	Provide protected space from natural elements
Pile	Maintain integrity under tolerable external forces	Provide vertical and lateral support to the building
Earth	Resist to vertical and lateral movement of piles	Provide support to piles through friction and rock bed

<u>In-Depth Analysis</u>: Once the function and behavior of involved structures in the case are discussed, an in-depth analysis will be provided to reveal that this case bears many characteristics of a complex phenomenon, i.e., many interrelated systems, causality, randomness, emergence, and so on.

Simulation of the factors and the construction process leading to failure, such as those shown in Figure 2, will be developed to demonstrate a series of temporal and spatial factors that contributed to the collapse of the building. The simulation will demonstrate the event from a multidimensional perspective, including 2D/3D models, underlying engineering principles, site constraints, schedule and cost considerations, change of soil conditions, and other associated factors.

For example, the multidimensional simulation is intended to reveal that the collapse of the building was a result of many spatial and temporal factors: 1) construction of an underground garage after the construction of the building, 2) excavated earth stockpiled on the other side of the building, 3) no support provided to shore the earth after excavation for the underground garage in order to prevent a landslide, and 4) storm-caused changes in soil properties. If the underground garage was built at the same time as the apartment building, the excavated earth was stockpiled somewhere else, sufficient shoring was provided immediately after excavation, or the weather was perfect, the collapse may not have happened. Thus, through such an experience, students may gain a deeper understanding of concepts such as: emergence, the phenomena, "building collapsed," is a result of many subsystem interactions; randomness, factors such as weather and the contractor's budget situation are often nondeterministic; and multi-causality, obviously there were multiple causes for the failure of the building.

<u>What-If Scenarios</u>: After going through the analysis, students will go through a series of "what-if" scenarios by using simulation. For example, if there had been no heavy rain after the excavation, what would have happened? Or if the reinforced concrete wall of the garage on the building side had been immediately constructed, would the wall have provided sufficient support to resist the movement of the building? These scenarios will not only help students to reinforce the experience gained through the analysis process but will also enhance their ability to apply the

SBF framework and complex systems concepts when developing solutions to a complex problem.

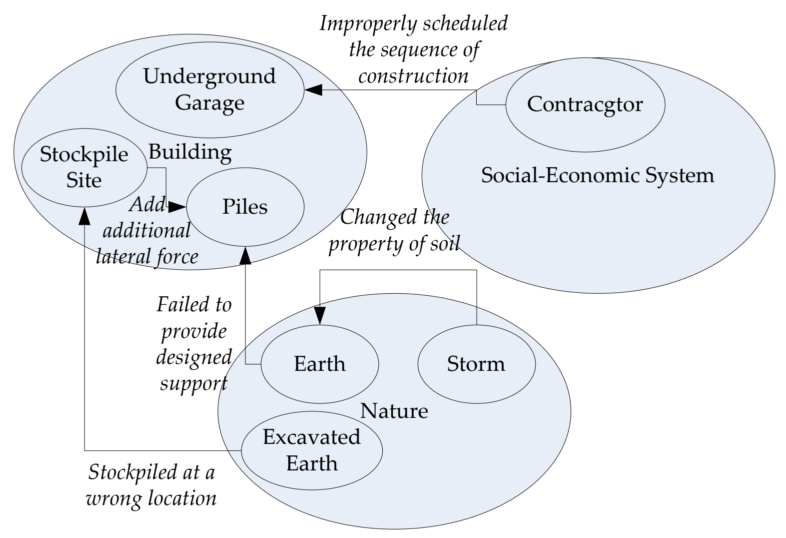


Figure 3. A systems perspective of the case.

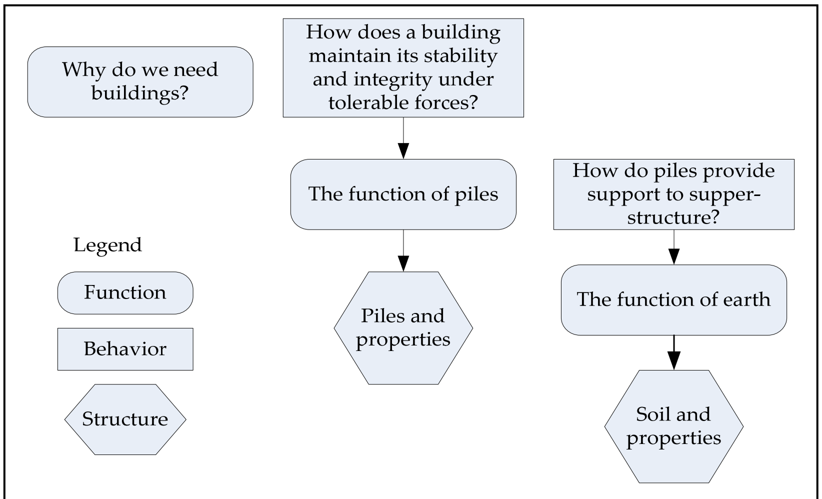


Figure 4. Example of hypermedia presentation structure.

Learning Scaffolding: Learning scaffolding is intended to assist students, with different learning styles, preconceptions, and prior knowledge, with learning concepts of complex systems. Chunduri et al. [38] found that addressing the learning styles and prior knowledge of students has a positive impact on learning in construction. Jacobson [23] discussed a Scaffolding Connected Knowledge Framework (SCKF) to provide scaffolding support for students learning complex concepts and achieving conceptual change. Ideas from SCKF will be applied to this research.

Three types of scaffolding will be provided in CMVE: presentation, conceptual, and problem solving.

Presentation scaffolding will be achieved by using different presentation forms for the same concept. In this study, text, symbols, 2D/3D simulation, animation, audio, and video will be used to present concepts and cases and to cater to different learning styles. Conceptual scaffolding will be implemented by using mini-lessons [23] and conceptual explanations [39] [23] in order to address students' prior knowledge and preconceptions. Problem-solving scaffolding will be provided through exemplary cases on solving construction engineering and management problems. These cases will be structured using the SBF framework to reveal core complex systems concepts and rationale for solutions.

Evaluation

The basic evaluation method used in this research is experimental study, in which the learning results of the control student group will be compared with the learning results of the experimental student group. The control group will use the traditional teaching methods, and the experimental group will use the developed CMVE tool. It is expected that the large sample size in the two participating universities (sample size is greater than 90 at each university in three semesters) will generate reliable results from statistical point of view.

Table 2. Planned Experiments

Location	**Group**	**Pre-experiment** (Case 1)	**Experiment** (Case 1 and 2)	**Post-Experiment** (Case 3)
University 1	Controlled	KST_{c11} and PST_{c11}	-	KST_{c12} and PST_{c12}
	Experimental	KST_{e11} and PST_{e11}	-	KST_{e12} and PST_{e12}
University 2	Controlled	KST_{c21} and PST_{c21}	-	KST_{c22} and PST_{c22}
	Experimental	KST_{e21} and PST_{e21}	-	KST_{e22} and PST_{e22}

Notes: 1) KST – Knowledge Structure Test; PST – Problem-Solving Test; 2) Subscript of KST and PST has three letters or numbers. The first letter, c, or e, represents control group, or experimental group respectively. The first digit is either 1 or 2, represents University 1, or University 2. The last digit is either 1 or 2, representing a pre-experiment test or a post-experiment test.

Table 2 shows a series of planned experiments. There are two types of tests: knowledge structure tests (KSTs) and problem-solving tests (PSTs), at the pre-experiment phase and the post-experiment phase. The experiment phase is the time period when the experimental group will be exposed to the CMVE environment, and the control group will use regular learning materials. The pre-experiment and post-experiment stages refer to the time period before and after the experimental group are exposed to CMVE, respectively. KSTs are designed to elicit students' conceptual structure about spatial and temporal complexity in construction engineering and project management. PSTs are designed to understand students' skills for solving complex problems. In total, three cases will be developed. The Shanghai case described in C.1 will be Case 1, which will be used for the pre-experiment phase tests. After the tests, Case 1 will be reused in the experiment phase, in which in-depth analysis and "what-if" scenarios will be provided to assist students' learning. In addition, a second case will be developed for experiment as well. The post-experiment phase test will use a third case for tests.

The purpose of these tests is to determine the students' existing knowledge about spatial and temporal complexity associated with construction engineering systems and skill sets to solve construction engineering problems. Then, after the experimental group has gone through cases using CMVE, post-experiment tests, including a KST and a PST, will be administered to the same groups of students.

Both concept maps and interviews will be employed to elicit students' knowledge structures during the pre-experiment phase KST. Concept maps are used as an effective assessment tool of students' knowledge structure [40] [41] in many disciplines, including engineering [42]. Considering the pros and cons of the two major concept mapping techniques, i.e., the fill-in-the-map method and the construct-a-map method, the authors will take a hybrid approach, i.e., the students will be given a list of concepts (for nodes and links) that are more than they need to construct the concept map of a particular subject; and they will be allowed to use their own concepts if the concepts are not included in the provided list. The authors will conduct training sessions for students before asking them to construct any concept maps. In addition, expert concept maps will be developed by the authors for comparing with the student maps. In addition to concept maps, interviews will also be administered to students in the control and the experimental groups. Concept maps are good at eliciting conceptual knowledge, concepts of systems, and relationships between systems. Interview-based techniques [8] will provide a complementary way to elicit students' understanding about function and behavior of a system.

Table 3. Test Parameters for Hypotheses 1-A to 1-C

Hypothesis	**Test Parameter**
1-A	1) The number of structures, behaviors, and functions (SBF) associated with KSTs of the experimental groups is significantly larger that the number associated with the control group. 2) There is a significant difference between the KSTs and the PSTs of the experimental groups before and after the experiment. 3) The concept map scores of the experimental group are significantly better that those of the control group.
1-B	1) The number of structures, functions, and behaviors associated with PSTs of the experimental groups is significantly larger that the number associated with the control group. 2) The difference in terms of the number structures, functions, and behaviors between the expert PST and the experimental group PST is smaller than the difference between the expert PST and the control group PST.

Results from the student concept maps and the interviews will be measured by students' use of SBF [8], as well as the concept map scores. These results will help the PIs to determine students' prior knowledge and misconceptions, which can be used to make corresponding learning arrangements for students in the next step and as a baseline to determine any improvements after experiments using CMVE. After the experiments, students will complete post-experiment tests of the same test concepts by using concept mapping and interviews. The pre-experiment and post-experiment tests will be compared and analyzed to measure the effectiveness of using CMVE.

PSTs will be performed by asking students to develop solutions to construction engineering problems and provide rationale for their solutions. The solutions and the rationales will be analyzed by determining the number of SBFs. In addition, the solutions will be evaluated using qualitative analysis and compared with expert solutions.

Table 3 illustrates the test parameters that will be measured for testing Hypotheses 1-A and 1-B. Repeated measure ANOVA tests will be employed to compare the learning effects among the groups for each test concept. This design will allow comparisons between the two groups at different phases. Additional comparisons will be performed between universities.

Expected outcomes

This research seeks answers to the following research questions associated with the effectiveness and the feasibility of CMVE. The following hypotheses will be tested based on the empirical data collected from the participating classes.

<u>Research Question:</u> The proposed environment may lead to conceptual change from a static, structure-oriented perspective of complex spatial and temporal phenomena to a more dynamic and function/behavior-oriented perspective. It is always a question as to how effectively the proposed environment can realize comparable results with traditional case-based learning or problem based learning. Such results should be reflected by observable facts, including: 1) an enriched understanding of complex phenomena and 2) an improved capability to explain complex phenomena and solve complex problems. This research will focus on the following hypotheses.

<u>Hypothesis 1-A</u>*:* Since students using the proposed environment, an experimental group, will experience complex phenomena by going through a set of selected and purposefully designed cases which are intended to trigger their conceptual change, it will be reasonable to hypothesize that those students will demonstrate a different conceptual structure about spatial and temporal phenomena than students who don't use the proposed environment (i.e., a control group). 1) The researchers expect that if the experimental group is tested before and after they use the proposed environment; their conceptual structures will show a significant difference. 2) In addition, if the experimental group, after using the proposed environment, is compared with the control group, there will also be a significant difference in their knowledge structure about spatial and temporal complex problems.

<u>Hypothesis 1-B:</u> Similar to the reasons presented in Hypothesis 1-A, Hypothesis 1-B theorizes that the experimental group will demonstrate an improved capability of handling complex spatial and temporal problems in construction engineering and project management. This improved capability will be reflected by: 1) if both groups are presented with the same spatial and

temporal cases, students in the experimental group will tend to provide significantly more function and behavior explanations than students in the control group, and 2) if both groups are asked to provide a solution to a spatial and temporal problem, the students in the experimental group will provide a solution that bears more characteristics of the one developed by experts.

Anticipated impacts on engineering education

The usage of the combination of case-based learning with 3-D animation of the engineering failure cases to assist students' inductive reasoning process for learning complex problems is a novel teaching-learning method. The findings from this project will enrich our knowledge of inductive engineering education in learning complex construction engineering systems. The outcomes will help to close gaps between learning well-structured engineering theories and developing solutions to ill-structured, real-case scenarios by adding inductive reasoning and complex systems thinking to traditional deductive-driven engineering education. It is also anticipated that the success of the project will help to identify factors that enhance sharing virtual teaching resources via existing cyber infrastructure, which will lead to increased integration of cyber infrastructure resources into engineering education.

The authors expect the outcomes of the project will significantly impact the teaching-learning model of construction engineering concepts. In addition, the proof of concept and data produced through the proposed work will be used to inform the design of a scalable teaching/learning environment, the CMVE environment, which could be expanded to multiple institutions in the next phase. Finally, an assessment model can be obtained to evaluate the impact of sharing cyber-based education resources through partnerships of multiple construction engineering schools at different geographic locations.

The proposed work, combining the strengths of remote access field trips, virtual simulation/animation, and cyber infrastructure, is expected to result in a hybrid system that can have an impact on not only conventional construction education but also on distance learning. Since field experience is a critical education component for science, technology, engineering, and mathematics (STEM) disciplines, the findings from this project will provide useful data for a range of engineering education disciplines. Results of the project will directly impact the teaching and learning of a wide variety of construction engineering courses, which rely heavily on students' spatial-temporal cognition skills of building systems and construction processes.

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