

Applying Structure, Behaviour and Function (SBF) and Discrete Event Modelling to Construction Education: a Pilot Study

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Students in construction engineering and management need to develop good understanding about the complexity of construction processes, including the structural behavior of buildings in their partial configurations, and the latent and stochastic effects of decision-making during construction. In this study, a learning environment, called Case-base Active Knowledge Environment (CAKE), was developed using a case of the construction of a high-rise residential building. The case shows that the building collapsed due to many factors; such as: improper construction sequence, poor selection of staging areas, and bad weather conditions. Through this case, computer animation illustrated the interactions of the elements of different systems, including building, natural environment and social-economic systems, and how and why these interactions led to the failure of the building. The information illustrated by the animation was organized based on the structure-behavior-function theory and discrete event modeling. A pilot experiment to test the use of CAKE was conducted with four graduate students. Through this experiment, it was observed that using CAKE could enhance students' ability to correctly explain the case and use more non-structure concepts. However, there was no clear indication that using CAKE could improve students' ability to predict the interactions and dependencies of different systems.

Key Words: Construction, Case Study, Visualization, Structure-BehaviorFunction (SBF), Discrete Event Modeling

Introduction

Problem Statement

Complexity in engineering systems is well recognized (Suh 2005). Spatial-temporal complexity of building systems and their construction processes are at the center of many complex engineering and management issues.
Due to the complex nature of the construction processes, "many of the students who make it to graduation enter the workforce ill equipped for the complex interactions, across many disciplines, of real-world engineering systems" (Wulf and Fischer 2002). Consequently, costly design errors and misinterpretations of design documents become a frequent issue in construction projects; thus, enhancing students' ability to understand such complexity will help them to evaluate the project risks, potential delay, rework and claims (Rudy and Hauck 2008). For civil, building, and construction engineering students, having such ability 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.

Objective

The authors are motivated by the existing research findings in case-based learning or reasoning (CBL/CBR), learning complex systems, and computer visualization technologies. These findings provide an opportunity to construct a different pedagogical approach for teaching and learning subjects of construction engineering and project management. The approach is based on discrete event modeling (DEM) and a structure-behavior-function (SBF) framework to model and visualize causal relationships of construction and building systems.

Design of a SBF Hypermedia Learning Environment

SBF and Discrete Event Modeling

Hypermedia has been applied extensively in undergraduate education, such as simulations of complex engineering processes (e.g., Feisel and Rosa 2005) and engaging students in learning functions and behaviors of systems (Liu and Hmelo-Silver 2009). In addition, computer technologies are used to simulate field trips (e.g., Haque et al. 2005, Arrowsmith et al. 2005), and in problem-based learning (e.g., Taradi et al. 2005). Furthermore, Dorst and Vermaas (2005) provided a theoretic foundation to structure case studies using SBF.

However, a SBF framework needs to be instantiated in the context of this research. In construction engineering and project management, “Structure” refers to physical structures such as buildings or highways, stakeholders 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. “Behavior” refers to the mechanism used by 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 loads, the wall will remain at a standstill. Finally, “Function” refers to the purposes of the structures. Focusing on behaviors and functions may reveal hidden interactions between systems’ elements which represent a major cognitive challenge for students to appreciate the spatial and temporal complexity in construction engineering.

Since a construction process can be viewed as a series of discrete events, the reconstruction of a case study using discrete event modeling and visualization of system interactions can have great potential to enhance students’ ability to understand the complexity in construction. A classic discrete event system can be defined by 1) a set of input values, 2) a set of states, 3) a set of output values, 4) internal transitions, 5) external transitions, 6) output functions, and 7) time (Zeigler 2000). The SBF framework provides guidelines on the sequence and emphasis for presenting learning materials, while DEM provides a logic foundation for students to reason the sequence and interaction of events. Hence, the complementary nature between DEM and SBF may provide a conductive learning environment for students.

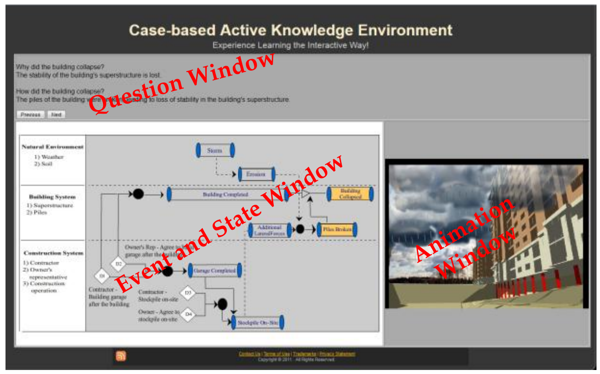
Visualization

The visualization environment is called Case-based Active Knowledge Environment (CAKE) (Figure 1), which consists of three main windows, the question window, the event window, and the animation window. The question window has two parts, a display window to show questions and answers according to why and how a certain event happens, and a navigation tool to allow users to look for a particular event. A default sequence is set by the instructor or the designer of the case study. The flow sequence of the questions through each event is predefined. Students can use “Previous” and “Next” buttons to navigate through the process, or use a second mode, which is using the tree structure in the navigation window to search for a particular event.

The event window displays systems/components, events, and interactions. Major systems and components are shown as blocks on the left-hand side, which can be further expanded to show the components in each system. The entire system is placed on a time scale and events are represented as bars. A decision is also modeled as an event, using a diamond shape, to differentiate it from regular events. The occurrence of an event can be a result of another event(s), or decision(s). A solid circle is used to represent “AND” logic, while a regular circle represents an “OR” logic. When an event is chosen, the path(s) that leads to its occurrence will be highlighted. In this way, students can see the causal relationships of components relevant to each event. In addition, events on screen are grouped using broken boundary lines to show their association with systems. The latent effect of a decision refers to some unexpected consequence of the decision.

The animation window illustrates the behavior of a system in relation to the questions being asked. For instance, when the question "Why was the building tipped over?" is posted in the question window, the animation window will show an animation of the site and the building collapsing. At the same time, an event in the event window is highlighted, together with a chain of events leading to it.

Figure 1: Design of hypermedia



Case Description

The case study used is about a high-rise residential building in Shanghai, China, which collapsed during construction. The building was built before the construction of a nearby underground garage. During the construction of the garage, the contractor decided to stockpile excavated earth on the other side of the building. Then, a storm hit the area and lasted for a few days causing erosion in soil on the side of excavation adjacent to the building. Consequently, the piles of the building foundation broke and the building was tipped over.

The goal of the case study is to help students understand that the cause of the unfortunate event cannot be simply attributed to one factor, such as broken piles. There are several systems, namely the building, the construction, and the nature, which interacted together and led to the final consequence. At the same time, this case shows students that, as construction professionals, some of their decisions may have a latent effect depending on the behavior of other systems.

Experiment Setup

An announcement was first made to a graduate level class, Principles of Construction Scheduling, in the Spring semester of 2012, inviting students to participate in an experiment including pre- and post-tests. Four students eventually volunteered and participated in both tests. The experiment is designed to complete in two phases, which are nearly three months apart. The first phase, "pre-test", is designed to elicit students' existing knowledge status about building structure, basic soil mechanics, and construction project management; while, the second phase, "post-test", is designed to measure the degree of change in the students' understanding of the case after using CAKE. Before conducting the pre-test, a general information session was organized to explain the goals, procedures and other relevant issues to students. Both tests consisted of two sections: the first section consisted of questions related to the basic information of students in order to be able to match the results of both tests; while the second section contained six questions related to the case study. In the pre-test, the case study was only presented as a diagram with all the systems labeled on it. The learning process was not timed.

Assessment

The goal of the assessment was to determine if the students' skills of describing a complex construction case were enhanced after using the CAKE. Two assessment were designed (Table 1). These skills include:

1- Describing the case from a system perspective, including all factors that contribute to the failure of the building.

2- Predicting the behavior and interactions among the natural environment, the building, and the construction systems.

Table 1
Design of assessment

	Goal	Subject	Test	Assessment Point
Assessment 1	Elicit students' ability to explain the failure of the building	Why did the building collapse?	Questions 1 and 2 in the pre- and post-tests	1) Capability of using concepts from three systems; 2) Capability of describing the process led to the failure of the building; and 3) Tendency of using more functional and behavioral concepts.
Assessment 2	Elicit students' ability to predict the behavior and interaction among systems	Describe the case if conditions changed.	Questions 3, 4 and 5 in the pre- and post-tests	Capability to connect concepts of different systems and changes in behavior under certain conditions.

Analysis and Results

Analysis

Two common methods were applied in this experiment to analyze the results obtained from the pre and post-tests, namely concept maps and term analysis. Concept maps have been used in the assessment of teaching and learning by many studies (e.g., Chunduri et al 2010). In that study, students were asked to provide a description about a certain topic and then concept maps were constructed by the researchers based on that description. With regards to the scoring of the concept maps, different methods were reported in literature which dealt with this issue. Yin et al. (2005) proposed a scoring scale of 0 to 3 to assign scores for concept map propositions; where "0" is given for wrong propositions, "1" for partially wrong propositions, "2" for correct but insignificant propositions, and "3" for correct and significant propositions. Novak and Gowin's (1984) scoring criteria gives one point to each correct proposition, five points for each valid level of hierarchy, and 10 points to each correct and significant cross link between different concept groups, but only two points to correct links which are not significant. In this study, a similar scoring system was applied. Correct propositions from the same system were given one point, while correct propositions using concepts from different systems were given three points. Other aspects of the students' concept maps were not analyzed.

Term analysis was used by Hmelo-Silver et al. (2000) and Hmelo-Silver and Pfeffer (2004) through an SBF coding system. Structure concepts refer to part of the involved systems that include concrete concepts describing natural environment, the building, and construction and its process, as well as abstract concepts describing relevant engineering and scientific events such as time and lateral force. If a statement refers to some property of structure, for example the stability of the foundation or weight of the structure, each property will be counted once. The same structure concept appearing multiple times is counted once. Behavior concepts refer to how any relevant structure concepts behave to realize some purpose. For example, soil erosion happens when water content in the soil increases to a certain level. False statement about a behavior will not be counted. Behavior concepts, if they refer to the same behavior, are counted once. Function concepts refer to the purpose of a structure. For example, pile foundations are used to support the stability of superstructure. Function concepts, if they refer to the same functions, are counted once too.

Findings and Results

In Table 2, students' ability to describe the case from a system perspective was measured using the SBF technique. The table shows the number of different systems concepts used by each student in tests, as well as the number of correct propositions created by each student, and how many of those propositions were connecting different systems. Finally, a total score was calculated for each student, in each test, based on the scoring criteria described in the previous section. From the table it appears that all students have used more behavior concepts after learning the case via CAKE, while the use of structure terms also increased in two cases. Overall, the post-tests showed much higher scores than the pre-tests. These results showed that after students used CAKE, they tended to use more concepts to describe the case. It is also interesting to observe that students significantly increased the number of correct propositions and the use of concepts from different systems after the use of CAKE. These observations seem to suggest that there is a positive relationship between the use of CAKE and the students' ability of properly explain the failure of the building. However, it is also observed that using the CAKE did not obviously increase the application of function concepts. This was clearly reflected in the students' explanation, where most descriptions were about what were involved and what had happened to those involved. Maybe students never felt necessary to explain why they were involved because the reason was obvious to them.

Table 2
SBF test results

	Test	No. of Structure Concepts		No. of Behavior Concepts		No. of Function Concepts	No. of Correct Propositions		Pair from Different Systems		Total Score
Student 1	Pre-Test	8	25%	7	29%	0	4	125%	1	700%	6
	Post - Test	10		9		0	9		7		23
Student 2	Pre-Test	8	0	5	20%	0	4	50%	1	300%	5
	Post - Test	8		6		0	6		3		9
Student 3	Pre-Test	6	100%	5	100%	0	1	1100%	0	infinite	1
	Post - Test	12		10		1	11		3		15
Student 4	Pre-Test	10	0	7	29%	1	4	74%	2	50%	8
	Post - Test	10		9		0	7		3		16

Regarding the assessment of the second skill, the following tables were developed using the answers of questions four and five in both pre and post-tests (see Table 3 and 4). In these questions, different scenarios were provided to students and they were asked to predict what would happen in the case based on these scenarios. First, the tables show whether the students provided correct answers to the questions or not. Students' answers were grouped into three categories (see "Answer"), where correct answers are assigned the value of "1", unanswered "0", and incorrect "-1". Second, similar to the assessment of the students' ability to describe the case, the number of both the correct propositions and the pair of propositions from different systems were calculated and each student's total score was derived in a similar manner to the previous assessment. According to the results, it is difficult to determine if the use of CAKE was able to enhance the students' ability to predict the different systems behaviors. Out of the eight cases, only one case showed a change from -1 in pre-test to 1 in post-test and another case changed from 0 to 1. On the other hand, there were two cases in which a wrong prediction was made or a wrong prediction was not corrected after using CAKE. Maybe it is because making proper prediction required additional information that CAKE did not provide, or that the student was not ready to perform such prediction; thus, probably it was not proper to ask students to make predication in such an experiment. It was also observed that students did not provide much explanation as shown by the number of correct propositions. However, it was also observed that students used more concepts from different systems after using CAKE.

Table 3
What-If test results

		Answer	No. of Correct Propositions		Pair from Different Systems		Total Score
Student 1	Pre-Test	0	1	200%	1	100%	3
	Post - Test	-1	3		2		7
Student 2	Pre-Test	-1	0	Infinite	0	Infinite	0
	Post - Test	1	2		2		6
Student 3	Pre-Test	1	2	100%	1	0%	4
	Post - Test	1	4		1		6
Student 4	Pre-Test	0	2	50%	1	-100%	4
	Post - Test	0	3		0		3

Table 4
What-If test results

		Score	No. of Correct Propositions		Pair from Different Systems		Total Score
Student 1	Pre-Test	1	2	100%	2	100%	6
	Post - Test	1	4		4		12
Student 2	Pre-Test	1	1	200%	1	200%	3
	Post - Test	1	3		3		9
Student 3	Pre-Test	-1	2	0	0	Infinite	2
	Post - Test	-1	2		1		4
Student 4	Pre-Test	0	3	0	1	200%	5
	Post - Test	1	3		3		9

Conclusion and Future Work

Construction is a complex process. Learning such a process is a challenge faced by construction students. In this study, the authors proposed using systems theory in the form of a structure, behavior and function framework, as well as discrete event modeling to make interactions and dependencies of system components explicit to students. A case study approach was applied and four graduate students participated in the pilot experiment. It was observed that using CAKE could lead to the enhancement of students' ability to correctly explain the case by using more non-structure concepts; however, there was no clear indication that the use of CAKE improved students' ability to predict the behavior of and interactions among different systems.

Nonetheless, due to a small sample, no definitive conclusions can be drawn. Therefore, more tests with a larger sample size need to be conducted in order to determine the effectiveness of CAKE. Furthermore, comparisons of CAKE and traditional teaching techniques can be conducted to further test this new system. The results from these future tests can be very significant. If a positive relationship between the use of CAKE and the students' ability to correctly explain construction cases is established, it can change the way how case studies in construction engineering and management are taught in the future.

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