Using an Analytics Engine to Understand the Design and Construction of Domestic Buildings

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Abstract:
Understanding domestic building technology is fundamental to the learning and teaching of building and construction. Like any subject dealing with technology and process, domestic construction makes most sense when it can directly be experienced by the learner. One possibility is to develop the rich visual and behavioural modelling capabilities of advanced video game engines such as Crytek CryENGINE®2. This game engine has been modified to perform as an analytics engine specific to the design and construction of domestic buildings. The system is currently being developed and trialled as a learning and teaching resource with a large cohort of undergraduate construction management students. Users are required to source a variety of tools within the game environment which they use to analyse a range of domestic building representations. The analytics are used to investigate specific design and construction options and diagnose deliberate design faults or building regulation breaches incorporated into the models. Results of this project identify the key perspectives necessary to scope such a project; the critical aspects around which development of such a resource needs to articulate; and considers the separate evaluation processes required for the game development, the learning and teaching outcome and the project itself.
Keywords:
analytics, domestic construction, educational technology, video game engines

1 Introduction

Two recent reviews of undergraduate education in Australia identified that construction technology constitutes more than 20% of the first year architecture degree (Ostwald and Williams, 2008:126) and 25% of the building degree curriculum content (Williams *et al*., 2009:20). Understanding construction technology remains a significant part of the core skills and competence requirements for all relevant professional accrediting bodies in building and construction (see for example, RICS, 2009). In the UK, construction is a key concept in The Quality Assurance Agency for Higher Education subject knowledge benchmark statements for construction, property and surveying (QAAHE, 2008:4). In Australia, the integration of construction technology is identified explicitly as a Threshold Learning Outcome in the current Learning and Teaching Academic Standards project specific to building and construction (Newton and Goldsmith, 2011:5).

Traditionally, a significant component of construction technology curriculum has been delivered through exposure to work-based learning, project-based assessment drawn from contemporary industry practice and site visits to building projects currently under construction. The purpose of these forms of curriculum is to enable students to observe the process and technology of construction work in action. However, as class sizes increase, occupational health and safety regulations are tightened, potential site locations become more distant and the temporal nature of construction means there is only ever a minimal window of opportunity to witness particular aspects of technology, it has become increasingly infeasible to provide direct student exposure to the broad practices of construction technology in a realistic setting (Mills *et al*, 2006). Equivalent difficulties

face all vocational education programs in the built environment, where the practice situation involves dangerous and/or expensive process/technology contexts.

In such situations, the potential of replacing direct student exposure with a virtual simulation is apparent. In construction technology education, for instance, a number of previous initiatives have utilised a mix of Computer-Aided Design (CAD), QuickTime VR, video and multimedia as virtual substitutes for actual site visits (Horne and Thompson, 2008; Ellis *et al.*, 2006). Such initiatives certainly provide useful illustrations of the technical knowledge required, including (though generally indirectly) illustrations of relevant technical skills such as the scheduling of construction work tasks, project team management, and analysis of design defects. However, where knowledge-based learning generally can quite readily be demonstrated and assessed through written and oral tests, skill-based learning (competence) requires the student to practice and demonstrate actual activities in authentic situations.

Competence is fundamentally about the assessment of an individual's capacity to perform certain professional tasks in given situations in a particular way (Cowan *et al*., 2007). Currently neither actual nor virtual site visits are, of themselves, sufficiently interactive for competence-based learning outcomes then to be demonstrated by the student or directly assessed by the teacher. The question of how students might practice and demonstrate competence in core discipline-specific skills (such as construction technology), particularly where such skills are best exercised in a difficult practice setting (such as a construction site), is yet to be resolved adequately.

A classic approach to competence assessment in architecture is the design studio, in engineering it is typically the testing lab, and in other fields such as medicine it is the clinical placement. In building and construction technology one equivalent approach has been to create a form of, so-called, 'constructionarium' (Ahearn *et al*., 2005). A constructionarium is a controlled site setting where students under supervision work in teams to produce construction outcomes that range from building discrete brick walls, to short-span bridges and even simple buildings. Students experience, practice and can demonstrate (ie. be assessed on) the technical, process and managerial aspects of these construction activities. However, whilst they provide excellent learning experiences, the significant material and organisational costs associated with such projects renders them entirely impractical to apply across the curriculum more broadly and/or to large student cohorts.

One possibility is to replicate the constructionarium approach on a smaller scale and have students construct, say, 1:10 scale-models of buildings or their components (see, for example, Forsythe, 2009). Figure 1a illustrates one example of how first year students can use model building to demonstrate their competence in construction technology. It employs relatively sophisticated model-building skills to represent the technical and relational construction technologies of a typical domestic construction in Australia.

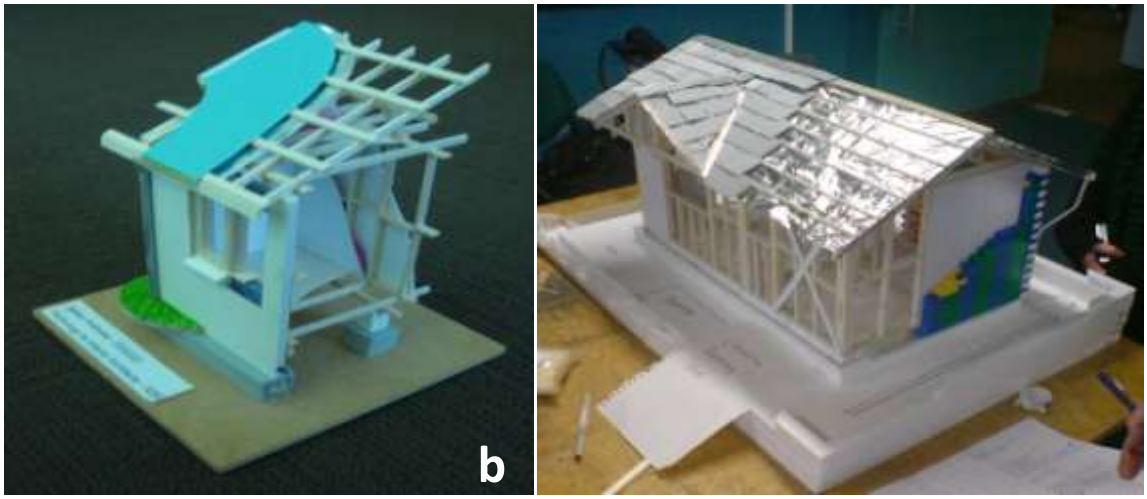

Figure 1a. A student 1:10 scale model outcome for a typical domestic construction exercise

Figure 1b. Another 1:10 scale model outcome that represents less sophisticated modelling skills

The use of such models is certainly a more viable exercise than actual site work, but its utility as a teaching method often depends as much on the model-building skills of the student as it does on their technical competence in construction technology. For example, Figure 1b illustrates another example of first year use of model building to demonstrate competence in construction technology. In this case the quality of the model building is far less sophisticated. It uses crude material representations (such as lego-bricks) that make it more difficult to demonstrate and assess the technical understanding of construction. This quality of modelling also makes it impractical to use the model as any basis for an analysis of the design and construction choices being made, through consideration of wind-loading/bracing, minimum spacing of rafters, effective timber jointing details, etc.

The aim of this paper is to articulate a current project to design, develop and evaluate the use of virtual reality technology to replicate the controlled site-setting and actual-scale nature of a constructionarium exercise, but with the same viability advantages that physical modelling has over actual site work. A key objective of the project is to deliver a level of immersion and interactivity in/with the virtual reality system that is sufficient to enable core construction technology skills (for example, the scheduling of work or the analysis of design/construction defects) to be demonstrated and assessed effectively and directly through the use of the system.

2 Why Choose Serious Video Games?

The most sophisticated interactive virtual reality simulation environments with practical application to teaching and learning are to be found in video games. Video games use high performance graphics engines to render moving photo-realistic scenes in real-time and 3D along with the potential for associated surround-sound audio and tactile feedback to a user who controls the action with a variety of input devices. Figure 2 demonstrates the visual quality achievable in the Crytek CryENGINE®3 game.

Figure 2. Real-time Scene Rendering in CryENGINE®3 (Wu, 2010:15)

The ‘action’ is in fact variously controlled not only through input devices, but also by the particular rules and properties ‘coded’ into the video game by the developer. Such coded rules and properties are now extremely sophisticated, and many incorporate models of real-world mechanical behaviours (‘physics engines’) that simulate physical properties such as mass, gravity, velocity, volume, etc. in exceptional detail. Objects in such games can variously be opened, pushed, bent, lifted, broken and/or be used to trigger a myriad of other actions. Artificial intelligence and social dynamics are also now being modelled and incorporated into video games to simulate agency and group behaviour in different game ‘actors’.

What is particularly timely about the potential development of video games for learning and teaching, is the recent development in video game technology that has resulted in the 'game engines' themselves (the kernel of coding used to drive a collection of actual game implementations) being made available on an open-source basis. Even the most powerful game engines are now relatively cheap to acquire for teaching and learning purposes, are intentionally configured to allow third party modifications to be created and embedded seamlessly into the game engine, and are increasingly supported online by a significant and committed community of users and developers (referred to as 'modders').

Several examples of 'serious video games' (a serious video game is one designed for a primary purpose other than pure entertainment, such as for learning and teaching) have now been developed as modifications to game engines across a range of game genres. For example, 'vehicle simulation engines' have been used to train and test vehicle operators from fighter pilots to crane drivers (Rouvinen *et al.*, 2005); 'strategy game engines' are variously used for teamwork and project management training; 'business simulation games' model economic and manufacturing environments. The current research project has focussed on a specific genre of video game known as a 'first person shooter' (FPS) game. FPS games are characterised by the use of an avatar which allows the user to see and be seen as a person would conventionally occupy a space (ie. bound to one's own body). Other game genres take a more abstract form of engagement (such as command-driven controls) or tend to focus more on the interactions and communications across a social network (such as in Second Life) rather than exercising specific technical competences.

3 The Concept of an Analytics Engine

Analytics involves the use of computer technology to access, transform, store, analyse and monitor information extracted from a variety of typically very large databases. For a study of the design and construction of a domestic house, for example, the analytics might involve mining, harvesting, analysing and visualising a representative range of data relevant to the particular instance of domestic house under review. Analytics seeks to extract and/or generate data relevant to a particular decision at a particular point in time in a particular location. Data such as building construction materials, statutory planning instruments, building codes, construction costs, design details, etc. The shear scope and size of existing data sets, both public and private, that might relate to any given construction project is already a matter for concern (Rumor *et al*., 2008).

It is already possible to store and access a range of relevant data through Building Information Modelling (BIM) (see, for example, Eastman *et al*., 2008). However, such information typically has to be pre-loaded into a model and the visualisation options available are then limited significantly by the CAD system itself. There are currency issues with any pre-loaded information and BIM is simply unable to make extensive use of the many and varied 'live' digital data streams increasingly available from video cameras, monitoring stations, laser scanning, geographic positioning systems, augmented reality and a multitude of web-enabled feeds. Last year alone, digital information grew to 988 exabytes. To be effective, any analytics must incorporate the same range of data sources otherwise available to the decision-maker, which includes data well beyond the capability of current BIM systems.

Our concept for an analytics engine is one where the full range of potential data sources can be accessed, interrogated and visualised in real-time. In that sense, an analytics engine for the design and construction of domestic houses would enable the user to completely construct and/or dismantle any instance of house in any site setting, to measure any physical property (from distance between rafters to the bending moments exerted in wall bracing due to wind forces), to inspect any design detail (including automatic sections), to reference current building regulations relevant to a particular situation, local authority planning legislation, weather records, etc., etc. – any source of information that might be of interest and relevance to the user.

The Crytek CryENGINE®2 game engine used for this research has all of that functionality potential. It is already the benchmark for graphical performance, with near-photorealism in indoor and wide-

open outdoor environments and extra-ordinary real-time special effects. This graphics capability is generally considered in terms of the visual realism it promotes, but it also means that no part of the interaction needs to be pre-recorded (canned). Every scene is freshly generated and able to be generated in whatever form a particular set of context variables dictate, in full stereoscopic 3D if required, on the full complement of graphics devices (even, now, down to the iPhone®). In addition, the game engine is able to interface with a range of Application Programme Interfaces (API's) including the multitude of live data feeds. This means it is now possible to modify every property, behaviour and minutiae represented in a video game based on user controls, calculations that result from user input and external data feeds. This might include the introduction of random events such as construction delays to simulated outcomes, dynamically changing details based on changes to building codes and/or explicitly modelling uncertainty using visual techniques such as blurring.

The critical question for this research is: How might such an analytics engine concept be implemented using the Crytek CryENGINE®2 game engine, for the particular purpose of supporting the learning and teaching of domestic building design and construction?

4 A Prototype Video Game-Based Analytics Engine to Understand the Design and Construction of Domestic Buildings

The design and development of any serious video game needs to be evaluated not just as a game but as a learning technology. This requires the standard design and production process for video games to be broadened to include consideration of the learning context – within what Luckin (2008:449) terms a "learner centric ecology of resources". New serious video game initiatives are beginning to temper just such an explicit and specific overarching design and evaluation framework (de Freitas and Jarvis, 2006). This framework takes the more general form of a structured and rigorous consideration of the context (including the resources available to deliver, access and support the game), learner specifics (including learner attributes and preferences), representation (the form or mode in which the content of the game is made manifest to the user – explicitly, implicitly, vicariously, etc.), and pedagogy (the theory and practice models that frame the learning activities) within which a learning technology is to be deployed.

A formal process of human factor analysis using focus groups and task analysis has been undertaken, along with an analysis of the learning needs of current students. For instance, the learning needs were assessed by reviewing the performance of several hundred students in their end-of-year examinations, to identify those topics where students were having problems and the typical mistakes they were making specific to construction technology. A small reference group of users has been established to trial prototype systems and evaluate various implementations. Formal evaluation of the current prototype is being conducted using a control group of students having no exposure to the video game, where the placebo is standard revision and tutorial support.

The prototype game implementation simulates the addition of each element of the construction process, from site excavation through to roofing. It is a multi-user environment where individual avatars are able to wander around and over the construction work, examining design details and following construction processes.

For example, Figure 3 is a screen grab showing two students interacting with the reinforcement and formwork just prior to pouring the slab. They can see how the work has been prepared, measure the distance between reinforcement saddles, test the capacity of the steel reinforcement under foot, check waste-pipe penetrations through the slab against best-practice guides, etc.

Figure 3. Screen Grab of Prototype Video Game Just Prior to Pouring the Slab.

As Figure 4a illustrates, the user is able to interact with the construction at any point, including when temporary bracing is still in place and as particular details between, say, bricks and timber and concrete are finished. Please note, the domestic construction used in this exercise is identical to the one used for the model-building exercise shown in Figure 1b. A building no larger than a standard garage has been used for this exercise overs several years in order to limit the size of the models students must produce. It is only when seen at relative life-size that the unnatural proportions of the dwelling becomes obvious. At any stage the user is able to interact with the model and demolish parts of it to expose design and construction details. The extent of the demolition is dependent on the natural physics of whether the user employs, say, just their body-weight, a sledge-hammer or a truck. Users are also able to check the sizes and spacing of timber members against building codes, analyse the implications of loads on different structural configurations, check construction steps against project programmes, etc.

One particular tool is illustrated in Figure 4b, where a section through another, more complex timber construction has been instigated by the user. The building is then slid apart across the line of the section and the ends of any affected members highlighted in red. This facility can then be used to check an actual (model) construction against a designed section detail provided in a set of drawings. The exercise requires students to interpret and compare both the actual as-built and the design drawings. It can be used to demonstrate and test a students' competency in reading technical drawings and interpreting an as-built construction.

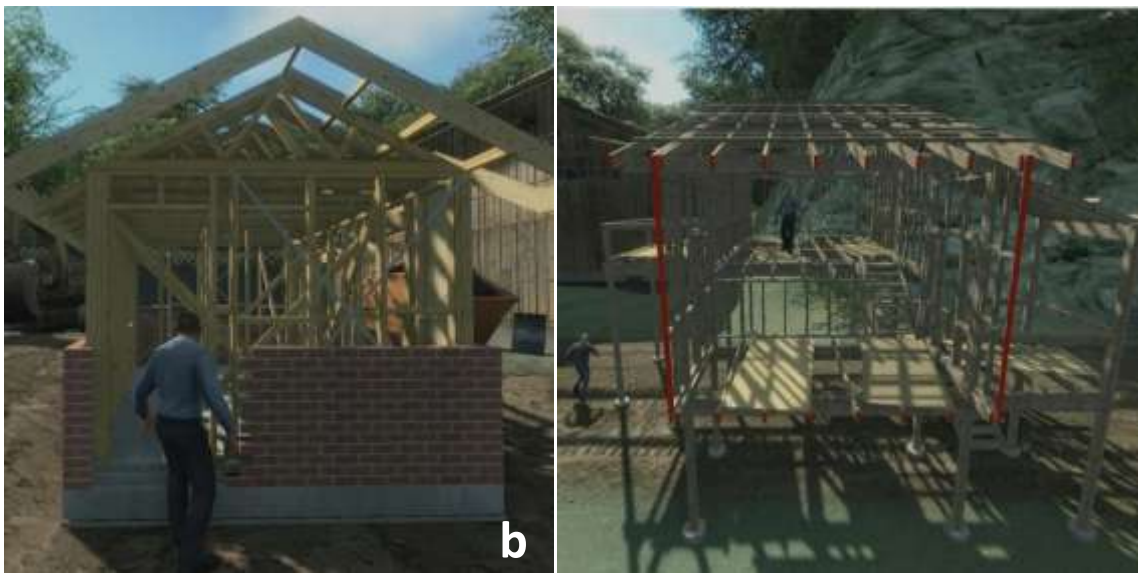

Figure 4a. Screen Grab of Prototype Video Game Just Prior to Removal of Temporary Bracing.
Figure 4b. Screen Grab of Prototype Video Game Showing Use of the Section Tool.

The current prototype can also be used to test a students' understanding of related issues, such as safe work practices, material storage and handling considerations, site security, environmental protection, wet-weather hazards, noise pollution, etc.

5 Research Methodology

The key strategy for this project is to harness a formalised and integrated approach to the design and production of learning and teaching technologies. The scoping of the project has been built around 4 discrete perspectives: the professional bodies that already operate competence-based standards in the building industry are involved to ensure that the mode and level of competence is appropriate to industry expectations; teaching institutions that offer courses in domestic construction are involved to determine the common threshold concepts that broadly need to be included within such a domestic construction technology subject; the key stakeholders in benchmarking national academic standards are involved to establish the broader context for an outcomes-based approach to assessment; and direct engagement with other professional learning contexts is included to determine the general scalability and alignment of this teaching and learning approach across the education sector.

The development of the video game has proceeded around 5 critical aspects: an integrated design and evaluation framework for learning and teaching technology development (including a variety of specific processes and methodologies), supported by a Steering Group of expert practitioners; extensive experience in the application of serious video game technology to building and construction education; detailed CAD models already developed to support the domestic construction technology subject; previous experience in the design and use of role-play and scale-model building; and the commercial interactive multimedia development expertise of our project team and reference group specific to teaching and learning applications.

The game development will be evaluated in terms of both the technology and the learning and teaching. In terms of the technology, the system is being evaluated by a range of users including a formalised user/testing/development group comprising students and academics. Prototype versions are being made openly available with the offer of direct support to any institution that wishes to participate in the trials. The development of installation and training notes to support the game has been included in the project funding. There will be two distinct development cycles over a 24 month period, each of which coincides with the teaching session in which the domestic construction subject is delivered. At this point we are about to conclude the first cycle. The project reference

group includes external, commercial serious game developers who will undertake their own technical review of the system.

The learning and teaching outcome will be evaluated using case study and quantitative analysis. The case study will involve questionnaires and interviews with student, staff and industry participants. This aspect of the evaluation will draw directly from the notion of an ecology of resources used as a design and evaluation framework for education technology (see, for example, Luckin, 2010). The quantitative analysis will monitor the performance of students in the end-of-session examinations for the domestic construction subject. The past performance of several hundred students will be used to benchmark the performance of those students who use the game and those students who do not. Past performance has been analysed to identify those aspects of the curriculum where students perform poorly in the examination, and the typical mistakes they are making. A self-nominating group of current students has now been exposed to different combinations of issues through the game evaluation process, and the performance of those students will be tracked through to their examination performance. The comparative performance of each student between their mid-year assessment task and the final examination will also be compared across the user group and the control group (those students who have no exposure to the game). All participants will remain anonymous to the course lecturer and assessor.

The project itself will include two external reviews by an expert in the design and development of new technology applications in higher education teaching and learning. The external review will capture the experiences and perceptions of the relevant students, academic staff, support staff, professional bodies, government agencies and project team and complement the internal and on-going project design and development reviews.

6 Context and Discussion

The particular opportunity offered by serious video games to situate learning within an authentic professional context aligns this project directly with the development of professional knowledge and competence. Any framework that promotes and improves our understanding of the sociocultural context of and for professional practice will contribute to the broader consideration of learning as a situated activity (Wenger, 1998). Of course situated cognition is not without its critics (Vosniadou, 2007), and an approach that is exclusively sociocultural would undoubtedly ignore key cognitive aspects of learning and teaching. The focus of this project is on competence-based learning and assessment. It presumes that knowledge-based learning is a necessary precursor to skill-based learning. So, whilst we might never reach a definitive expression of competence in sociocultural terms alone, it seems equally inconceivable that competence is something that can ignore human dispositions and social constructs (Hager and Holland, 2006). The growing significance of competence in higher education requires that more urgent attention be given to how we might teach and assess skill-based learning in that sector. That is what this project primarily seeks to do.

In seeking to evaluate the efficacy of serious video games in a learning and teaching context, we must also guard against complacency in the face of seemingly ever increasing sophistication (and ‘reality’) in the simulation technologies available. Virtual reality technology is impressive, but it is patently not ‘reality’. The ‘experience’ of a construction site and the practice and demonstration of construction technology competences in a virtual environment does not equate in every respect to the same experiences and demonstrations on an actual construction site. The entailments of a virtual versus a real situation are both positive (the virtual situation can be controlled, is available, scalable, specific, etc.) and negative (the virtual situation is abstract, simplified, sanitised, etc.). This project will examine the strengths and weaknesses of serious video games as a replacement for actual construction project experience and physical model building/simulation.

In a similar vein, any learning performance improvement that might emerge from the trial of the video game must be qualified against the spike in enthusiasm, resources and the sheer novelty value of any innovation introduced into the classroom. The proof of any benefit as a learning and teaching technology will only come from a longitudinal study across large and heterogeneous student groups.

However, critical to such an examination is that the implementation of the learning tool (the video game) is as representative of the technical potential as is practical at that time. Collection of longitudinal evidence has now commenced, but the more immediate goal of this project is to design and develop a viable implementation/example of video game technology with which to drive such a study. The current focus therefore is on integrating and testing the overarching design and evaluation framework derived from Luckin (2008) and de Freitas and Jarvis (2006).

7 Conclusion and Further Research

Understanding construction technology is fundamental to the study of building and construction. It demands knowledge, skills and capabilities that are becoming increasingly problematic to deliver using traditional means. The potential of virtual reality in such a situation is apparent. Video game technologies have developed to the point where the most powerful and graphically advanced game engines are themselves now openly available and specifically configured to be modified by users. The possibility of adopting serious video game technology to directly support teaching and learning in construction technology is now a very real and practical one.

The broad concept developed in this paper is for an application of video game technology in the role of an analytics engine: where the full range of relevant data sources pertaining to a particular instance of domestic construction can be accessed, interrogated and visualised automatically. A prototype video game-based analytics engine has been developed using the Crytek CryENGINE®2 specific to teaching and learning domestic construction. That prototype has been described and its potential considered. A critical issue is the design and evaluation framework being adopted to ensure the technology is developed and incorporated as part of a learner centric ecology of resources. The research methodology is specifically framed to challenge and inform that design and evaluation framework.

This paper highlights the four discrete perspectives necessary to scope such a project (professional bodies, teaching institutions, national academic standards agencies and cross-sector learning contexts). It identifies the critical aspects around which development of such a resource needs to articulate (an integrated design and development framework, steering group of expert practitioners, serious video game experience, detailed digital models, experience in role-play and other forms of simulation and commercial interactive multimedia expertise). Separate evaluation processes are also considered for the game development, learning and teaching outcome and the project itself.

The need for some qualification of the claims and achievements of any such project is recognised, until such time as a broad-base of evidence over time has been achieved. In consequence, the paper takes a conservative stance on the potential of the technology and the current prototype game. Ultimately, however, the vision is for a video game where students will be able to demonstrate the full range of technical competence expected of them (mapping the construction process, planning the sequence of tasks, selecting a viable configuration of materials and design options, ensuring compliance with relevant building codes and regulations, coordinating the construction activities, teamwork, etc.).

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