LEARNING AND TEACHING DOMESTIC CONSTRUCTION COMPETENCE USING SERIOUS VIDEO GAME TECHNOLOGY

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ABSTRACT: *For the accreditation of standards in all vocational higher education learning contexts, the question of how to develop and assess competence is central. There are certain situations where relevant skills can be assessed in the workplace, but for most the only viable option is to simulate a practice setting in something like a workshop/studio, by modelling or through role-play. The possibility of replicating a dynamic workplace situation and the competences that go with it in an immersive virtual reality offers perhaps the first practical opportunity for large student cohorts to practice and assess technical competence in a robust and secure setting. This paper outlines a pilot project currently under development that seeks to develop a serious video game built in CryENGINE2 to enable first-year construction management students to learn and demonstrate their technical competence in domestic construction. A theoretical framework for the design, development and evaluation of serious video game technology is detailed, based on the various work of de Freitas and of Luckin. The project development to this point is described and illustrated. Learners playing the game are required to source a variety of tools which they use to deconstruct (demolish) a selected building model. For example, at the simplest level, they might use tools such as a virtual crow-bar or an excavator to dismantle a domestic house model piece by piece. Alternatively, using a form of forensic analysis, the learner is required to determine how particular domestic house models (constructed with deliberate design faults) may or may not fail to satisfy statutory and other building regulations.*

KEYWORDS*: Competence, Serious Video Game, Domestic Construction, Production Framework.*

1. SOME BACKGROUND TO LEARNING AND TEACHING DOMESTIC CONSTRUCTION COMPETENCE

Construction technology is a significant, core component of all undergraduate built environment degrees. In Australia it 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). A significant component of this construction technology curriculum traditionally has been provided through site visits to building projects currently under construction, where students can 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 construction technology in action, 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 where the practice situation involves dangerous and/or expensive process/technology contexts: invasive health procedures, high-technology manufacturing processes, special events and emergency response management, etc.

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 understanding required of architects and builders, including (though generally indirectly) illustrations of relevant technical skills such as the scheduling of construction work tasks, project team management and the forensic analysis of construction defects.

Whereas knowledge-based learning 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. 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). Neither actual nor virtual site visits are, as and 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. The same question also still applies to those students who might study to become a doctor, engineer, surveyor, or for any number of professional practice outcomes.

The classic approach to competence assessment has involved simulated or quasi- professional practice settings. For example, in architecture it is the design studio and in medicine it is the clinical placement. In building and engineering construction technology, one equivalent approach has been a form of, so-called, 'constructionarium' (Ahearn *et al*, 2005). A constructionarium, in this sense, is any controlled site setting where students under supervision work in teams to produce a construction outcome that might range from building a discrete brick wall, to a short-span bridge and potentially a complete (simple) building. In a constructionarium-type situation, students are able to experience, practice and (most critically) demonstrate (ie. be assessed on) the technical, process and management aspects of particular construction activities. Unfortunately, whilst constructionarium-type exercises provide excellent learning experiences, the significant material and organisational costs associated with such projects renders them entirely impractical to apply across the curriculum and/or to large student cohorts.

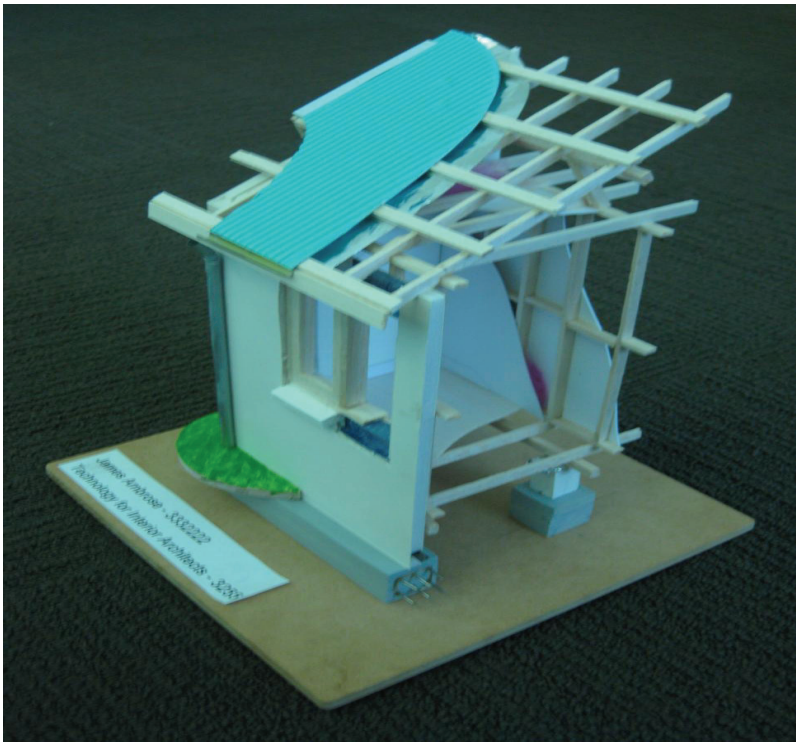

Figure 1: A student 1:10 scale model outcome for a typical domestic construction exercise.

One alternative to the full-scale constructionarium-type exercise is to operate on a smaller, more economic scale. For example, to have students construct, say, a 1:10 scale-model of some construction outcome or construction component in a workshop environment. Figure 1 illustrates the 1:10 scale model outcome for one student exercise which models a typical domestic construction in Australia. Such a modelling exercise is able to address both the process and the technical details of a simple domestic construction project (see, for example, Forsythe, 2009). The scale-modelling approach is certainly a more viable exercise than the constructionarium-type exercise in terms of the resources consumed/required, but its utility in learning and teaching terms often depends as much on the generic model-building skills of the student as it does on their technical competence in construction technology.

So, the basic question behind the pilot project described in this paper is the extent to which the controlled site-setting and full-scale nature of a constructionarium-type exercise might effectively be replicated using a

virtual reality technology in order to assess technical competence in a way that is more scalable across the curriculum.

2. A BRIEF CONTEXT FOR THE CHOICE OF SERIOUS VIDEO GAME TECHNOLOGY

The most sophisticated interactive virtual reality simulation environments 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. 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. Rules and properties are not fixed, but are available to be modified by game designers using tools supplied by the developers (see below in Section 4 for further detail). 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 equivalent 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 the group behaviour of different game 'actors'.

What is particularly timely about the potential development of video games for learning and teaching, is the recent initiative to make available the 'game engines' themselves (the kernel of coding used to drive a collection of actual game implementations) on a basis equivalent to open-source. Even the most powerful game engines are now relatively cheap to buy (or come free of charge), 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. This all is important, because it lowers the potential barriers to the deployment and uptake of video game technology by and within the teaching and learning sector.

Several examples of 'serious video games' (a serious video game is one designed for a primary purpose other than pure entertainment) have now been developed as modifications to game engines across a range of game genres. For example, 'vehicle simulation engines' have long 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 project described in this paper will focus 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 presents the first-person perspective that enables the player to see and be seen as a person would conventionally occupy a space (ie. bound by and to one's own body). Other similar game genres adopt either a more abstract form of engagement (such as the third-person perspective characteristic of games like Sim City, and entirely command-driven game controls) or tend to focus more on the interaction and communication capabilities across a social network (as is the case in Second Life worlds, for example).

The important context particular to this paper, however, is how the design and development of any serious video game might be evaluated not just as a game, but as a learning technology – and not just as a stand-alone learning technology but as part of a constellation of teaching and learning resources. In this regard, the standard design and production process for video games has to be broadened in scope to include explicit consideration of the teaching and learning context and within what Luckin (2008:449) terms a "learner centric ecology of resources". New serious video game initiatives are beginning to fashion such an explicit and specific overarching design and evaluation framework specific to the teaching and learning sector (de Freitas and Jarvis, 2006). This paper further develops such a theoretical framework.

3. A THEORETICAL FRAMEWORK FOR THE DESIGN, DEVELOPMENT AND EVALUATION OF SERIOUS VIDEO GAME TECHNOLOGY

The video game industry itself is massive, with a recent Nielsen Games survey of U.S. consumers showing that expenditure on video games now represents 5% of total household spending on entertainment – more than for books, films or music (NielsenWire, 2010). Hardly surprising then, that the video game industry now has in place a robust general framework for the overall production process (ie. the design, development, deployment and evaluation of video games – see for example, Adams, 2010). The typical framework adopts an integrated production approach that seeks to promote the key user requirements as critical success factors throughout a

traditional, strongly iterative, 'analysis-synthesis-evaluation' production process (Kirjavainen *et al*, 2007). That said, the learning and teaching context does introduce novel and additional factors into the production requirements of any technology application (Woods, 2004).

A structured approach to the production of a learning technology, it might be argued, is important so that lessons can be learned and applied going forward. However, few such frameworks with relevance to the more highly immersive video game technologies exist. Established, and more generic, learning technology production frameworks (such as TILT, CIAO! and Flashlight – see Oliver, 2000) tend to limit the scope of consideration to include just the educational outcomes that a learning technology is intended to address/promote (the pedagogical approach – pedagogy); the educational context within which it functions (how it is deployed – context); and how the technology functions *per se* (how the technology presents itself to a user – representation).

Recently, de Freitas and Oliver (2006) have extended the generic production frameworks for games-based design and production to a four-dimensional model. That evaluation framework is now also being used "… to support the development processes of training games applications to ensure that the game will have efficacy for targeted learner groups." (de Freitas and Jarvis, 2006:3). Figure 2 presents the four-dimensional framework.

Four Dimensional Framework	
Learner Specifics Profile Role Competencies	**Pedagogy** Associative Cognitive Social/Situative
Representation Fidelity Interactivity Immersion	**Context** Environment Access to learning Supporting resources

Figure 2: A Four-Dimensional Framework for Game-Based Learning (de Freitas *et al*, 2010:72).

According to de Freitas *et al* (2010), these four dimensions are necessary to provide the full complement of considerations relevant to a teaching and learning application that builds on the immersive character of FPS (and similar) games. In a way that parallels previous frameworks, this model requires consideration of the pedagogy (the theory and practice models that frame the learning activities), context (including the resources available to deliver, access and support the game), and representation (the form or mode in which the content of the game is made manifest to the user – explicitly, implicitly, vicariously, etc.). However it also extends this consideration through a more explicit inclusion of learner specifics (including learner attributes and preferences).

The 'fourth' dimension in this case requires presumed and actual learner activities during the use of the learning technology to be profiled and analysed explicitly. Profiling the user directly is of particular significance in the design and evaluation of serious FPS games, because, in a sense, the interaction between the user and the game 'is' the learning experience. Matching the learning activities possible within any given serious FPS game with the required learning outcomes and then scaffolding the learning pathways is critical.

Whilst the de Freitas and Oliver (2006) four-dimensional framework for game-based learning already includes elements of pedagogy, context and learner specifics, those elements are included from a particular (and limited) point of view – the technical development of a particular serious game technology implementation. A broader theoretical framework is required to capture the range of educational technologies, implementation strategies, available learning resources, types of learners and timeframes. For a broader perspective setting this paper has adopted the concept of a learner-centric ecology of resources, as proposed by Luckin (2010). In this theory, the learner is placed at the centre of three dimensions: the skills and knowledge to be learned, the resources available to support learning, and the environment within which learning occurs (see Figure 3 for a representation of this model).

In broad terms, this framework includes the same general elements for consideration: pedagogy, context, representation and learner specifics. In this model however, the relationship of each dimension to the learner is processed/filtered through a particular delivery medium: knowledge (pedagogy) is filtered through the particular design of the curriculum; available resources (context) are filtered through the particular way those resources are administered and made available to the learner; and the environment is represented to the learner (representation) through the particular organisational/technological structure within which they learn. Luckin (2010) also articulates a further dimension for all considerations (represented in Figure 3 by the grey box surrounds to each element), that recognises each aspect emerges from and impacts upon the broader historical/cultural background against which they must be set. The significance of this historical shadow to each element (the history of experience that impacts upon how the various elements interact) is still to be demonstrated empirically, but certainly in principle the existence and the importance of this wider cultural perspective needs to be recognised if possible in the game production process.

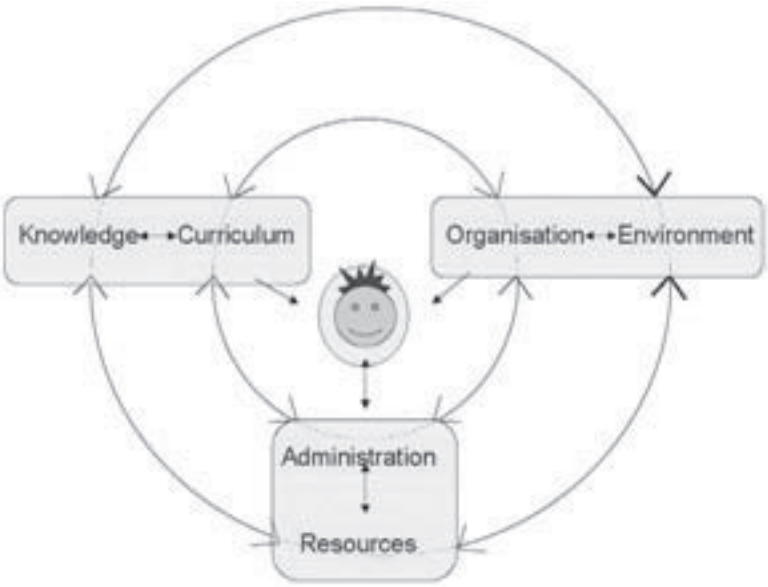

Figure 3: The Learner Centric Ecology of Resources (Luckin, 2008:453)

The current pilot project is following previous examples of how the notion of an ecology of resources, linked to the tools and techniques identified through the de Freitas and Oliver (2006) model, can be used as a design and evaluation framework for education technology (see, for example, Luckin, 2010). However, this particular pilot project will also relate very directly to the development of professional knowledge and competence – see for example Eraut (1994). Fortunately, the ecological framework seems entirely in keeping with most models of professional competence, and 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). In particular, it extends the research program proposed in Chaiklin and Lave (1996:30) to "focus on the content of and the ways people participate in changing social practices singled out for study because they appear to lie at the heart of the production and reproduction – the transformation and change – of the sociocultural order." In other words, the particular opportunity offered by serious video games to situate learning within an authentic professional context is critical.

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 is given to how we might teach and assess skill-based learning in that sector.

Returning to the concluding statement of Section 1 above, the basic question driving this project is the extent to which a virtual reality technology enables specific technical competence to be assessed in a way that is scalable across the curriculum. In doing so, however, 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 lacks serendipity, is abstract, simplified, sanitised, etc.). It is important, therefore, to examine the strengths and weaknesses of serious video games as a replacement for actual construction project experience. Of course it need not be an either or replacement. A particular advantage of video gaming technology is the relative ease with which a game designer is able to adjust and balance these entailments to suit a particular context.

4. A DESCRIPTION OF THE PILOT PROJECT DEVELOPMENT TO THIS POINT

A pilot project is currently in development, adopting the hybrid development framework as outlined in the previous section. A full articulation of that framework and how it is being applied is beyond the scope of this paper, but a broad specification and description of the game prototype now follows.

The implementation has been developed as a 'first person shooter' (FPS) game based on the CryENGINE2 video game engine. The choice of an FPS genre is considered in Section 2 above. The choice of CryENGINE2 is a consequence of our having designed and implemented a number of teaching-based and research-based initiatives using this (or directly equivalent) platform(s) in the past. For example, Lowe (2008) details the use of a FPS application used in a first-year architecture studio on design development and representation, at the University of New South Wales. This studio has run over several years and successfully involved hundreds of students in the use and modification of a serious video game application. Lowe and Goodwin (2009) details one of various applications where a FPS game engine has been used by the authors in a research context.

CryENGINE2 is also appropriate to the current application because it features more advanced graphical, physical and animation technologies than many others. For example, Figure 4 demonstrates the quality of graphic representation possible using CryENGINE2, and the goal of the current project. Image A is taken directly from http://wonderlandblog.com/ and Image B from http://forum.i3d.net/. In this case the modelled buildings have been fabricated using corrugated sheeting for the roof, with timber structural elements and large sheet cladding, which would suit the intended narrative structure of the game very well (see below).

Figure 4: Two examples (**A** and **B**) of the graphic capabilities of CryENGINE2, specific to domestic construction.

The proposed FPS game will replicate the current physical scale modelling activities of first-year Construction Management students studying domestic construction technology (refer again to Figure 1). In the first instance, however, the interactive construction of models will not be possible and student interaction will be restricted to the demolition of existing models in the game. Thus, the broad game narrative has been developed around the use of various high-definition building information models imported into the CryENGINE2 environment. A range of domestic buildings that model a variety of foundation, floor, wall and roof construction options in detail will eventually be incorporated. Each imported model represents a different form of domestic construction, and is generally being replicated and placed across a range of site conditions within the gaming environment.

The construction options to be included contain a mix of correct and problematic technical solutions for each particular site context and construction combination. Learners playing the game are required to source a variety of tools which they use to deconstruct (demolish) a selected building model. For example, at the simplest level, they

might use tools such as a virtual crow-bar or an excavator to dismantle a domestic house model piece by piece. The use of such tools in this way will enable students to practice and demonstrate their understanding of how different building examples are constructed, through the subsequent production of process maps and schedules of the work tasks specific to the building models they selectively deconstruct and subsequently reverse engineer. Students essentially demolish the buildings and then produce a report on the findings of their analysis.

Alternatively, using a form of forensic analysis, the user will be required to determine how particular house models (constructed with deliberate design faults) may or may not fail to satisfy statutory and other building regulations. The forensic approach will use a further range of specially designed virtual game tools to provide such things as x-ray views of wall constructions, sample testing of concrete finishes, etc. Using the information gleaned from such tools, students are required to diagnose and account for any failures/incorrect construction details/poor work practices expressed again in terms of the process maps and schedules that builders are expected to produce in practice. All of the virtual game tools are modifications to existing 'weapons' (such as swords modified to become crow-bars), 'vehicles' (such as trucks modified to become cranes), and 'material parameters' (such as adjusting opacity to simulate x-ray vision). The modification involves existing models of objects in a game (say, a sword or a truck) being visually modified to look like a crowbar or a crane and adjusting the relevant physical properties/behaviours of the objects (as registered in the game) accordingly.

For example, Figure 5 shows a screen-grab of one model already incorporated into the pilot game. This model was first created in as a conventional Building Information Model (BIM) using Sketch-up and ArchiCad. The BIM approach allows actual construction details and properties to be included, and for the final CAD model to represent individual building components in significant detail. The model is then imported into a prepared CryENGINE2 environment and multiple learners/users are then able to roam around the environment and examine each model (and other users) in real time. In this particular case, one user has employed a simplified cutting device to demolish and expose critical elements of the building, including details of the upper floor construction and window/wall joints. The result is equivalent to the modelling approach used with physical scale-models, as illustrated in Figure 1. In this case, however, the learner must select the cut-backs to reveal particular construction details in order to make a judgment on the choice of construction technology employed.

Figure 5: An example screen-grab from the pilot project, courtesy of Andrew Wallace (Lara Calder Architects).

Teacher and tutors will be able to deploy the developed system in a variety of ways. They may wish simply to make the system available to students to complement traditional teaching and learning material. Alternatively, they might teach the knowledge and skills required using conventional methods and employ the system specifically for the assessment of technical competence. The goal, however, is for the system to become a primary teaching and assessment tool within a broadly problem-based learning approach. In any event, extensive documentation, examples and case study material will be developed and made available to other institutions and analogous

discipline groups along with support for the necessary academic development required to incorporate the approach into existing curriculum effectively. The more teachers/tutors who become active users of serious video game technology, the easier it will be for a community of practice to support various development activities. Online support, in the form of community discussion lists and open forums, is already an established practice for the gaming community.

5. OTHER ISSUES AND FUTURE DIRECTIONS

Any high-end computer application is going to raise a number of concerns and problems for potential adopters at the institutional, teacher/tutor and learner levels. At the learner level, there are always issues of equity raised when students are required to use a novel learning technology because not everyone relates to a particular technology intuitively. Care will be taken to provide the necessary exercises and tutorial material specific to the game implementation that many students need to scaffold their effective use of such technologies. There is already a substantial body of online tutorial material associated with the generic interface and use of CryENGINE2 available within the public domain. More specific tutorial support material for the domestic construction technology application will be developed as part of the second phase of system evaluation.

The main challenge for the dissemination of this technology is likely to be at the institutional level. Serious video game technology puts particular demands on computer capabilities, particularly in terms of the graphics and processing power. Particular attention will be given to the production of documentation aimed at the technical computer support required for the deployment and subsequent maintenance of relatively sophisticated video game engine applications across a range of different computer lab configurations. The project group are encouraged that they have been able to facilitate over 250 first year students to utilise a complete suite of the software required, using a significant range of personal laptop configurations, including Mac and several Windows operating systems. Effective download speeds and the amount of internet traffic generated by such high-end graphics do, however, remain an issue.

Ultimately, although the technical development of such a game is rather more ambitious, students will be provided with the opportunity to source a variety of building components (and materials) which they will then be required to assemble into viable domestic house constructions. In this way, 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, etc.). Buildings completed by the students in this way could then be included as part of the set of building information models placed in the game for analysis (and review) by their peers and teachers.

For the accreditation of standards in all vocational learning contexts, the question of how to develop and assess competence is central. There are certain situations where relevant skills can be assessed in the workplace, but for most the only viable option is to simulate a practice setting in something like a constructionarium/studio, by modelling or through role-play. This opportunity extends across all professional education disciplines: in the built environment it might relate to work practices on a construction site; in health, to triage work in an emergency situation such as an explosion on an underground train; in engineering, to work in remote or treacherous locations such as capping deep-sea oil wells; in science, to work in restricted areas such as a nuclear power-station; in defence, to work on expensive facilities such as a submarine; in business, to work in the service sector such as event management; in education, to work in classroom layout and design; and so on. The possibility of replicating a dynamic workplace situation and the competences that go with it in an immersive virtual reality offers perhaps the first practical opportunity for large student cohorts to practice and assess technical competence in a robust and secure setting.

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