Developing a 4-dimensional interdisciplinary learning environment for construction industry professionals

Final report 2016

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Peter Sampson: Manager Special Projects, The University of Queensland. Peter was instrumental in providing support, particularly in the early stages of the project.
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<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>2D</td>
<td>two-dimensional</td>
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<td>3D</td>
<td>three-dimensional</td>
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<td>4D</td>
<td>four-dimensional</td>
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<tr>
<td>AACA</td>
<td>Architects Accreditation Council of Australia</td>
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<tr>
<td>AASA</td>
<td>Association of Architecture Schools of Australasia</td>
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<tr>
<td>ADBED</td>
<td>Australian Deans of Built Environment and Design</td>
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<tr>
<td>AEB</td>
<td>Advanced Engineering Building</td>
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<tr>
<td>AMSE</td>
<td>Advances in Management Science and Engineering</td>
</tr>
<tr>
<td>ANZ APAP</td>
<td>Australian and New Zealand Accreditation Procedure for Architecture Programs</td>
</tr>
<tr>
<td>ASA</td>
<td>Architectural Science Association</td>
</tr>
<tr>
<td>GUI</td>
<td>graphical user interface</td>
</tr>
<tr>
<td>HERDSA</td>
<td>Higher Education Research and Development Society of Australasia</td>
</tr>
<tr>
<td>NEC</td>
<td>National Education Committee of the Australian Institute of Architects</td>
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<tr>
<td>NSCA</td>
<td>National Standard of Competency for Architects</td>
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<td>OLT</td>
<td>Australian Government Office for Learning and Teaching</td>
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<tr>
<td>TEQSA</td>
<td>Tertiary Education Quality and Standards Agency</td>
</tr>
<tr>
<td>TLO</td>
<td>threshold learning outcomes</td>
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<tr>
<td>UniSA</td>
<td>University of South Australia</td>
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<td>UoN</td>
<td>The University of Newcastle</td>
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<td>UQ</td>
<td>The University of Queensland</td>
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Executive summary

Project context
Work-integrated learning has been suggested as a means to apply and learn disciplinary knowledge and skills in a real-world context. Yet tensions exist between the opportunities afforded by the workplace and the demands of placing large student cohorts in that workplace while ensuring equitable learning experiences and pedagogical rigour. Students in construction-related disciplines, in particular, require access to building sites so they can contextualise their learning. Lack of access is a problematic issue. This suggests opportunities to take alternative approaches and provide the benefits of work-integrated learning through simulated real-life contexts. To improve alignment between theory and practice, this project has developed an interactive digital learning environment based on time-lapse 3-dimensional (that is, 4-dimensional or 4D) visualisation and other resources associated with the design and construction of The University of Queensland’s (UQ) Advanced Engineering Building (AEB). The 4D environment provides a realistic context for simulated problems that activate student learning because it uses a collaborative problem-based approach to enhance critical thinking skills. The 4D environment is flexible: it can be used across different learning activities and disciplines. It also enhances the learning experience by developing observation, reflection and collaboration skills.

Project aim
This project aimed to address problems associated with the provision of a realistic, practical and interdisciplinary experience for students in construction-related professional disciplines. The primary objective was to address this aim through the development of an interactive, interdisciplinary 4D digital learning environment. Using the 4D environment across different disciplines allowed the project team to develop and assess different pedagogical ambitions and learning activities. The project also reintroduced some benefits of work-integrated learning back into the curriculum.

Project outputs, deliverables and resources
Completion of the project has resulted in three main deliverables: (i) teaching resources, (ii) technical resources and (iii) research publications. Teaching resources include the 4D Construction Learning Environment, an online environment that provides self-directed open access to construction-related documentation and photographic surveys that visually capture the AEB construction process over time. Teaching resources also include a project website that details the project development and six learning activity case studies. Technical resources include a 4D Construction learning environment development guide, which provides technical guidelines for the development of similar 4D environments. Project...
outputs also include four peer-reviewed conference papers, a poster presentation, five university presentations and an online webinar presentation.

Project impact
The project has had an immediate impact on team members who were required to develop innovative teaching approaches to best utilise the 4D environment, and to then respond reflectively to the ongoing student experience. The new curricula engaged students in a variety of learning activities and assessment strategies across different disciplines and year levels but within existing course aims and professional accreditation frameworks. The project also had a direct impact on students involved in the trials. Evaluation results demonstrated that the 4D environment had a positive impact on students’ understanding of the construction process; it also facilitated collaborative learning and helped to contextualise theoretical material. Project dissemination activities, which were aimed at encouraging broader adoption and maximising exposure, included presentations at academic conferences, professional events and networking opportunities.

Project approach
The project utilised 75 high-resolution, 3D digital photographic surveys undertaken at one-to two-weekly intervals (four dimensions) throughout the construction of the AEB. The digital surveys had been captured and processed into a prototype 4D environment, which was funded by a UQ Teaching and Learning Strategic Grant. This project redesigned the prototype graphical user interface (GUI), incorporated other resources associated with construction (such as drawings and contract administration documents) and developed additional resources, including time-lapse videos and interviews with key personnel. The project then developed a variety of immersive learning activities, based on ‘factional’ building contract and project management resources, interviews and problem-based learning scenarios, to activate student learning and enhance the real-life context.

Key findings
The 4D Construction Learning Environment:

- provides academics with a flexible platform for curriculum development across different construction-related disciplines, programs and year levels
- enhances students’ understanding of construction processes, and a gives them a means to learn collaboratively and contextualise theoretical material
- would be enhanced through inclusion of additional case studies and tutorials to explain elementary technical terminology and construction processes
- could be extended to other construction-related disciplines, programs and trades
- should be evaluated for its impact on critical thinking and work-readiness, and its capacity to integrate new 3D laser scanning technology and virtual reality software.
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1. Project context

1.1 Project context
Addressing the imbalance between theory and practice to produce graduates who can engage effectively in their chosen professional settings is a recently recurring theme in higher education (Kek and Huijser 2011; Litchfield, Frawley and Nettleton 2010). Work-integrated learning, where students apply disciplinary knowledge and skills in a real-world context, is one approach that seeks to address this issue (Billett 2009; Orrell 2011). However, in construction-related industries such as architecture, the ability to contextualise learning as a realistic experience is hampered by the dangerous, fragmented and litigious nature of the industry (RCBCI 2002; Safe Work Australia 2012). Also, the tertiary sector has limited involvement in construction-related research. Innovations in the industry, therefore, have a tendency to be retained as proprietary knowledge for competitive advantage. Conversely, the generic body of professional knowledge has a tendency to remain static, standardised and largely theoretical (Johnson 1972; Macdonald 1995), with academics reporting that they have difficulty in maintaining an industry-relevant contemporary knowledge base (Ostwald and Williams 2008).

Much has been made in the higher education literature of the advantages of work-integrated learning, both as a means to apply the disciplinary knowledge and skills, gained in a classroom, in a practical real-world context (Billett 2009; Smith 2012), and as a means to engage students in a real work environment (Orrell 2011). However, tensions also exist between the opportunities afforded by the workplace and the demands of placing large student cohorts in that workplace while ensuring educational validity and pedagogical rigour (Lester and Costley 2010). This suggests that there are opportunities to provide work-integrated learning through alternative approaches such as a technology-enhanced medium (Keppell, Suddaby and Hard 2011). Computer-simulated virtual reality environments linked to gaming technology have been developed as educational platforms, but these environments offer limited contextual realism and practical detail. An alternative approach is to create a virtual environment based on digital photographic images captured across the course of a ‘live’ construction project.

The challenges facing the construction industry
The construction industry is a significant sector of the Australian economy. In 2008–09, construction accounted for 6.8 per cent of Australia’s gross domestic product (GDP) making it the fourth-largest contributor to GDP. In the same period, 984,800 people or 9.1 per cent of the workforce were employed in construction-related activities, making it the fourth-largest employing industry in the country (ABS 2010). The sector also makes a small, but growing, contribution to national export earnings, primarily in the area of specialist architectural and engineering consultancy services (DFAT 2011). At a broader socio-environmental level, the construction industry has a further considerable impact on quality...
of life and the sustainability of that way of life, principally through the design of safe, liveable and energy-efficient buildings and urban environments. Having a strong and innovative construction industry is, therefore, an important foundation for Australia’s future.

Recent studies, however, suggest there are several fundamental flaws in the structure of the industry. In 2002, the Royal Commission into the Building and Construction Industry (RCBCI) described the industry as having a highly complex and competitive structure that limited innovation and contributed to poor productivity. Furthermore, the Commission noted that new construction projects were designed and managed on an individual basis and drew on a disparate range of skills that varied throughout the life of the project. The Commission concluded that the transient and multidisciplinary character of construction projects, together with the fragmented nature of the industry and adversarial procurement methods, affected the capacity for innovation and continuous improvement across the construction supply chain (RCBCI 2002). Recent industry figures and academic studies indicate that little has changed. There continues to be a high number of small firms operating in the industry and a high degree of specialisation (IBISWorld 2012). There is also continued concern about the capacity for innovation, particularly in relation to collaborative practices (Dossick and Neft 2010), knowledge management (Sheriff et al. 2012) and the integration of new technology (Love et al. 2011; Love, Edwards and Wood 2011).

The challenges facing education for the construction industry

In an extensive survey, Ostwald and Williams (2008) explored changes in the structure and content of architectural programs across Australasia, and the future challenges facing architectural education. The study concluded that curriculum ‘overcrowding’ (too much material), curriculum ‘drift’ (course isolation from foundational knowledge) and curriculum ‘fragmentation’ (non-design courses perceived to lack relevance) have undermined the teaching of core professional skills in architecture programs. Construction technology, one of four main curriculum areas, had maintained a relatively consistent weighting at 19 to 20 per cent of coursework offered in an architecture program; however, the demands on technical content had changed significantly. There was also a perception among academic staff that maintaining industry-relevant knowledge was a problem. In a study of the advantages of immersive learning environments for engineering students, Cameron et al. (2009) found that the loss of industry placements was having a further impact on the level of insight and appreciation of design and operational issues among undergraduate students.

Another issue for the education of construction industry professionals is an expectation that graduates will be able to operate effectively as members of multidisciplinary teams. The Oswald and Williams (2008) study reported that the design and assessment of group work was a growing educational challenge. This finding was reinforced by Tucker et al. (2014) who established that there was limited emphasis on the teaching of teamwork skills in architecture and related design programs. Academics also had limited understanding of
what leads to effective teamwork and how to design curricula that would enhance the learning of teamwork skills.

Finally, several studies have explored game-based computer-simulated virtual reality learning environments. De Freitas and Neumann (2009), for example, reported that the self-directed nature of computer simulations had the capacity to empower learners. There is, however, still a need for structured activities and academic interaction to support the acquisition of primary knowledge before more open-ended exploration can be effective. Marcelino et al. (2010) found the level of user interaction was a major strength of computer-simulated environments. While an avatar navigating through a virtual world is interactive, navigating in learner teams through a live construction site provides a level of real complexity that further enhances a sense of collaborative immersion and relevant experience. More recently, Nadolski et al. (2012) argued that computer simulations support the acquisition of higher-order skills more efficiently and effectively than traditional learning methods, although they acknowledge the high initial costs and the need for research on how effectively knowledge and skills are transferred in different practical settings. To date, no studies have been found that focus on the development of a 3D learning environment using digital photographic images of a ‘live’ construction process over time (four dimensions), and none have been found that compare computer-simulated environments with photographic digital learning environments.

1.2 Project background

In December 2013, a project team representing architecture and civil engineering at The University of Queensland (UQ), construction management at The University of Newcastle (UoN), and architecture at the University of South Australia (UniSA) was awarded a two-year $220,000 Australian Government Office for Learning and Teaching (OLT) Innovation and Development Grant, referred to hereafter as ‘the project’. The project was designed to build on an existing OLT-funded 3D digital learning environment for process engineers developed by Professor Ian Cameron and others (Cameron et al. 2009).

The project also used an existing series of 75 high-resolution, 3D digital photographic surveys undertaken at one- to two-weekly intervals (four dimensions) throughout the construction of UQ’s AEB. The 75 surveys had been processed into an initial 4D environment prototype called the 4D Construction Learning Environment Version 1. Dr Chris Landorf, Professor Ian Cameron and Professor David Williams undertook this preliminary prototype development through a $20,000 UQ Teaching and Learning Strategic Grant awarded in 2010, supported by additional $17,500 UQ Faculty of Engineering, Architecture and Information Technology Teaching and Learning Strategic Funding awarded in 2012.

Version 1 of the 4D Construction Learning Environment provided self-directed access to the 75 photographic surveys, visually capturing the construction process over time. The project set out to expand the prototype’s usability and expand its functionality, so the project
incorporates other resources associated with the design and construction of the AEB, including drawings, contract documents, time-lapse videos and interviews. The project also integrates ‘factional’ contract and project management resources, and interviews with key members of the AEB design and construction project team, to enhance the real-life context. These improvements expand the existing 3D images into a multi-user 4D environment. These additional resources are now available in the 4D environment using a drop-down menu.

Learning activity case studies have been developed to describe the various teaching approaches trialled as part of the project. These approaches vary from using the 4D environment as a simple demonstration tool during a conventional on-campus lecture through to simulating problems to activate student learning (Francis and Shannon 2013), using a collaborative problem-based learning approach to enhance critical thinking skills (Kek and Huijser 2011). Learning activity case studies and a 4D environment development guide are available through the project website.

1.3 Project aim

The aim of this project was to address problems associated with providing a realistic, practical and interdisciplinary experience for students in construction-related professional disciplines. To address this aim, the primary project objective was to develop an interactive, interdisciplinary learning environment using 4D time-lapse digital images of a live construction project.
2. Project approach

2.1 Conceptual framework

The 4D environment adopted an ‘exploratory learning’ pedagogical model (de Freitas and Neumann 2009) derived from Kolb’s (1984) ‘experiential learning’ model. Kolb’s original four-stage model defined a cycle of learning from concrete experience, to observing and reflecting on that experience, to forming abstract concepts, before testing in new situations that in turn become concrete experiences. In Kolb’s model, experience relates exclusively to ‘lived’ experiences. However, technology-enhanced learning approaches may relate to virtual experiences gained through ‘transactional’ learning, or set tasks designed as a choreographed, often team-based, learning pathway.

Table 2-1: Summary of participating courses and learning activities

<table>
<thead>
<tr>
<th>Year and program</th>
<th>Course details</th>
<th>Learning activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1, Bachelor of Construction Management (Building)</td>
<td>Building Codes and Compliance (250 students mixed-mode, Semester 2 2015)</td>
<td>Evaluation of fire safety issues in an immersive learning context. Formal evaluation of student comprehension using codes, construction drawings and 4D environment.</td>
</tr>
<tr>
<td>Year 1, Bachelor of Construction Management (Building)</td>
<td>Construction Technology 1 (350 students mixed-mode, Semester 1 2015)</td>
<td>Demonstration of site safety issues and construction processes in a lecture context. Indirect assessment of student comprehension using construction drawings and activity sequencing in the 4D environment.</td>
</tr>
<tr>
<td>Year 2, Bachelor of Engineering</td>
<td>Reinforced Concrete Structures and Concrete Technology (250 students, Semester 2 2015)</td>
<td>Demonstration of concrete design and construction processes in a lecture context. Formal evaluation of student comprehension using construction drawings and activity sequencing in the 4D environment.</td>
</tr>
<tr>
<td>Year 3, Bachelor of Architectural Studies</td>
<td>Architecture and Technology (100 students Semester 1 2015)</td>
<td>Demonstration of services and sustainable design integration in an immersive learning context. Formal evaluation of team-based comprehension using construction drawings and the 4D environment.</td>
</tr>
<tr>
<td>Year 3, Bachelor of Construction Management (Building)</td>
<td>Construction Business Management (150 students mixed-mode, Semester 1 2015)</td>
<td>Evaluation of management actions in an immersive learning context. Formal evaluation of student comprehension using role-play, reflection, factional contract documents and the 4D environment.</td>
</tr>
</tbody>
</table>
To incorporate virtual experiences into the conceptual framework for the project, Kolb’s second stage was separated into exploration and reflection stages, creating a five-stage model that emphasised the expanded role of social interaction in the immersive learning experience. Within this framework, the 4D environment was used in a variety of ways across four disciplines and seven courses, from a self-directed learning resource to an immersive learning environment. A summary of the participating courses, programs and learning activities is provided in Table 2-1. A five-item Likert-type scale and open-ended evaluation questionnaire was administered to students in five of the seven courses, and in one course in consecutive years (refer to Section 2.3).

2.2 Research methodology

The project adopted an action research methodology (Easterby-Smith, Thorpe and Jackson 2008) to ensure feedback was incrementally collected, reflected upon and fed back into the developing 4D environment and associated curriculum design. The project was divided into the following four stages of approximately six months each:

- **Stage 1 Development (Semester 1 2014)** – investigated alternative teaching approaches, technology options, and access to construction documentation and key personnel; reviewed existing course curricula
- **Stage 2 Usability Trial (Semester 2 2014)** – established how best to integrate other resources into Version 1 of the 4D environment; devised new learning activities and assessment strategies; conducted a usability trial of Version 2 of the 4D environment; evaluated, reflected on and modified the environment to Version 3
- **Stage 3 Pilot Study (Semester 1 2015)** – embedded other resources into the learning environment; conducted Pilot Study trials of Version 3 of the 4D environment; evaluated, reflected on and modified the environment to Version 3.1
- **Stage 4 Evaluation (Semester 2 2015)** – conducted further Pilot Study trials of Version 3.1 of the 4D environment; evaluated, reflected on and modified the environment to Version 3.2; finalised the project.

The 4D environment technical specification

The 4D Construction Learning Environment was assembled from 75 time-lapse digital photographic surveys taken over the course of the construction of UQ’s AEB. The digital surveys were embedded in an existing GUI derived from Cameron et al. (2009). The resulting 4D environment prototype, Version 1 of the 4D Construction Learning Environment, was an offline, single-user application requiring access to Adobe® Flash® Player (a browser plugin for GUIs embedded in web pages) and approximately 80 GB of digital storage space.

The photographic surveys used a Nikon D200 digital SLR camera with an AF DX 10.5 mm fisheye lens, and AF-S DX VR Zoom-Nikkor 18–200 mm and 55–200 mm digital lenses for general photographic work. Digital images were taken every one to two weeks from a
variety of positions or ‘nodes’ spread horizontally and vertically across each level of the building during construction. Images were uploaded onto a computer at the conclusion of each survey. AutoPano Giga V2.6 software was used to stitch and render photographs taken at each survey node into large panoramic photos. PanoTour Pro V1.7 software was used for internode and equipment hot-spotting, and for exporting krpano panorama XML files. Krpano software provided the 3D panorama functionality. Finally, Microsoft® OneNote® software was used to digitally mark up the location of survey nodes on floor plans and a unique Python script program was used to calculate node coordinates.

While it was tempting to document every aspect of the construction process as frequently as possible, the project team determined that this would ultimately reduce the effectiveness of the final 4D environment as a learning tool. Incremental changes to the overall construction site and progress on important building elements would become imperceptible. Navigating through the site once the data had been built into the software would also be difficult. To achieve consistent and concise surveys over the course of the construction period, the following rules were applied:

- Avoid capturing redundant and repetitive processes that deliver minimal educational impact and increase the processing workload and file storage requirements.
- Conduct a test survey to become familiar with the site and determine the ideal survey locations.
- Avoid survey nodes on temporary structures that become unavailable later.
- Where a temporary obstruction does occur at a survey node, find the next best or closest location to continue the survey. Identify the original node to be revisited at a later point in time.

Comparison screenshots of Version 3 of the 4D environment are shown in Figure 2-1 (Survey 3 dated 7 June 2011) and Figure 2-2 (Survey 34 dated 7 March 2012). Figure 2-1 is taken from Level 2 and Figure 2-2 is taken from Level 5 of the AEB. Both shots are facing in the same south-west direction: Figure 2-1 is taken at the edge of the construction site and Figure 2-2 is taken from within the building itself. The timeline across the bottom centre-to-right of the screen allows students to move chronologically between surveys, the plan at the bottom left of the screen allows navigation horizontally between nodes on a particular level of the building, and the vertical bar between the plan and the timeline allows navigation vertically between levels of the building. A mouse can be used within the 4D environment to rotate each image 360 degrees horizontally and vertically, to zoom in on particular areas to better assess detail, and to enlarge the floor plan to assist movement around the building.
Figure 2-1: 4D Construction Learning Environment, Level 2 Node 6 dated 7 June 2011

Figure 2-2: 4D Construction Learning Environment, Level 5 Node 2 dated 7 March 2012
The 4D environment development process

Development of the 4D environment can be considered conceptually as a cyclical process of development, evaluation, reflection and modification. Figure 2-3 summarises the flow of processes involved in a single development cycle.

In practice, development of the 4D environment was considerably more exploratory than Figure 2-3 indicates. For instance, the project team regularly revisited the foundational processes, such as defining user needs, specifying learning activities and assessing learning, within a single cycle. Where possible, lower-level GUI design was adjusted during that cycle.

Since project inception, the 4D environment has been through three full development cycles (Versions 1 to 3). Regular reviews, including system and user tests of design, content and
coding performance, directed priority areas for change and improvement. Students taking part in Usability Trial and Pilot Study learning activities provided feedback on the 4D environment’s functionality and its impact on learning. This feedback has guided development of the content available through the 4D environment, as well as the design of the GUI and associated curricula.

**Usability Trial (4D Construction Learning Environment Version 2)**

Version 2 of the 4D environment application was successfully uploaded into the uqcloud in early July 2014, allowing multiple users to access the application simultaneously. This completed a key first milestone in the development cycle of the application. Preparation for this included revisions to the original prototype (Version 1) guided by quality control processes and design modifications to the original graphic format. Users required an Adobe Flash Player (version 9 or later) browser plugin in order to view and navigate the environment. Student evaluations from a usability trial at UQ were analysed before a project revision plan was created for Version 3 of the 4D environment.

**Pilot Study (4D Construction Learning Environment Version 3)**

A critical next development milestone was to convert the application coding and krpano viewer to HTML5 to create Version 3 of the 4D environment. This was a significant software development based on the need for greater flexibility, including access for a wider variety of mobile devices and no requirement for third-party plugins. HTML5 also assured greater longevity of the 4D environment because the code was more stable.

Version 3 went live for initial Pilot Study trials on 2nd March 2015, with all planned elements of the graphical user interface (GUI) incorporated and tested by the end of March. Student evaluations from Pilot Study trials at UoN and the UniSA were analysed before a mid-year and final project revision plan was created. Many of the suggested improvements, including easier navigation between survey nodes, and clearer access to construction drawings and documentation, were feasible within technical and project resource limits and were included in the final version.

**Final (4D Construction Learning Environment Version 3.2)**

The current and final version of the 4D Construction Learning Environment comprises:

- an interactive 4D environment that captures the whole-of-building construction process over a two-year period
- separate ‘limited views’ of the auditorium, atrium and terracotta façade construction processes
- a comprehensive set of other resources associated with construction (drawings and contract administration documents), time-lapse videos of key construction processes and interviews with key personnel to support the learning activities and assessment
- a document library search screen.
The 4D environment research plan

The research plan included the conduct of 13 one-hour interviews with key AEB design and construction project team personnel to capture real-life experiences. Each interview was recorded for editing into short (five- to six-minute) podcast and video teaching resources for inclusion in lectures, tutorials and/or workshop learning activities. Based on these experiences, a variety of self-directed activities and problem-based learning scenarios, supported by factional building contract and project management resources, were developed by project team members for each course listed in Table 2-1. Curricular design across the seven courses was also informed by professional accreditation and competency requirements. Immersive scenarios were used to support a more active in-class learning environment and flipped classroom pedagogical model (Francis and Shannon 2013). In-class activities focused on group and peer learning activities to engage students in problem exploration and problem-solving (Kek and Huijser 2011).

Project team members at the three partner institutions and students enrolled in each course listed in Table 2-1 then trialled the various versions of the 4D environment. Students from 7 one-semester courses from the architecture, construction management and civil engineering programs at UQ, UoN and UniSA were asked to complete an anonymous evaluation questionnaire (Appendix C) after they had completed learning activities that used the 4D environment. The questionnaire took approximately 10 minutes. The questionnaire was administered as a paper-based survey at UQ and UniSA. Because of the high proportion of distance learners, an electronic survey through Blackboard was used at UoN. The questionnaire examined issues relating to the 4D environment’s appearance, ease of navigation, contents and learning enhancement across four different programs, two modes of study and four year levels.

2.3 Results

In Semester 2 2014, an initial Usability Trial of the 4D Construction Learning Environment Version 2 was conducted with Year 3 Bachelor of Architectural Design students at UQ. The trial employed an in-class, scenario-based activity each week for four weeks. Scenarios required students to access the 4D environment and observe specific structural, environmental and construction issues. The aim was to engage students in team-based problem-solving, and reflection on how particular construction activities are carried out, and how specific building elements are fabricated. The scenarios also aimed to link those activities and elements to the 2-dimensional (2D) information communicated in construction drawings.

This was followed in Semester 1 2015 by Pilot Study trials of Version 3 of the AEB 4D Construction Learning Environment with Year 1 and Year 3 Bachelor of Construction Management students at UoN, and Year 3 Bachelor of Architectural Studies students at UniSA. The Pilot Study used the 4D environment as an in-class demonstration tool (Year 1 Bachelor of Construction Management at UoN), as an in-class demonstration tool and
resource for self-directed student learning (Year 3 Bachelor of Architectural Studies at UniSA), and as a context for immersive problem-based learning (Year 3 Bachelor of Construction Management at UoN).

Further Pilot Study trials of Version 3.1 were conducted in Semester 2 2015. The 4D environment was used as a context for immersive problem-based learning (Year 1 Bachelor of Construction Management at UoN), as an in-class demonstration tool and resource for self-directed student learning (Year 2 Bachelor of Engineering and Year 3 Bachelor of Architectural Design at UQ), and as a context for immersive problem-based learning (Year 2 Master of Architecture at UQ). Results from a five-item Likert-type scale and open-ended evaluation questionnaire administered to students are summarised below.

**Question 1 Appearance**

In response to Question 1, ‘Did you like the appearance of the learning environment?’, 36.6 per cent of students strongly agreed, and a further 55.2 per cent of students agreed with the question (Figure 2-4).

![Figure 2-4: Student evaluation responses to Question 1](image)

Positive open-ended responses were made about the realistic appearance of the site, rather than the appearance of the environment itself. Suggestions for improvement included increasing the size of the floor plan in the viewing pane and enabling different floor plans to be overlaid to show the relationships between them. This has been addressed in Version 3 of the environment. Both cohorts made further comments about image sequencing, and suggested that images showing particular views should be taken from the same nodal position in each survey, and on each building level. This would enhance user orientation from survey to survey but cannot be undertaken retrospectively. The variable vertical and
horizontal progress of construction activity also makes it a difficult undertaking for any future case study projects.

**Question 2 Navigation**

Question 2 asked ‘Did you find the learning environment easy to use?’: 26.2 per cent of students strongly agreed, and a further 54 per cent of students agreed with the question (Figure 2-5).

![Figure 2-5: Student evaluation responses to Question 2](image)

Navigation, or ease of use, generated significant written comment in the Usability Trial. Although the environment is intuitive, many students described it as ‘slow to load’, and commented that it ‘froze’, ‘stuttered’ or ‘crashed’ during use. The node selection function on floor plans was similarly problematic and there were difficulties with the chronological survey selection function. Specifically, adjustments to the timeline slider caused the view to zoom out and the node to relocate on the floor plan, which caused confusion and frustration. These basic functionality issues were addressed in Version 3 and there were fewer comments about ease of use in the Pilot Study. Several comments were made, however, about the inconsistency of node locations from survey to survey.

**Question 3 Content**

In response to Question 3, ‘Did you find the learning environment assisted your understanding of architectural technology/construction management, if so, why?’, 21 per cent of students strongly agreed with the question, and a further 58.4 per cent of students agreed with the question (Figure 2-6).
Despite appearance and navigational issues, the positive impact of the learning environment on students’ understanding of the construction process was almost universally supported in both the Version 2 Usability Trial and Version 3 Pilot Study. Open-ended responses indicated that the 4D environment provided more information than 2D photographs or opportunistic site visits, and was a useful tool for understanding the day-to-day operation of a construction site. Students gave positive feedback about their enhanced understanding of construction sequencing and the requirements of particular construction activities and specific building elements. Additional comments related to the way the 4D environment revealed the building structure and architectural detailing, while the zoom feature enabled valuable close examination of particular details. Students also indicated that the 4D environment aided comprehension through comparison because they could compare 2D construction drawings and 3D images. Suggestions for improvement included incorporating time-lapse videos of key construction processes to help bridge the one- to two-week gap between digital surveys.

**Question 4 Learning experience**

Question 4, ‘Did you find the learning environment enhanced the architectural technology/construction management learning experience, if so, why?’, resulted in 17.7 per cent of students strongly agreeing with the question, and a further 55.2 per cent of students agreed (Figure 2-7).
In their comments about the extent to which the 4D environment enhanced the learning experience, students referred to creating a positive link between theory and practice, bringing the construction process to life, and helping to consolidate theoretical material presented in lectures. Some suggested concepts explained in lectures became easier to visualise 3-dimensionally after using the 4D environment, while some in the Usability Trial commented that the 4D environment facilitated group collaboration and discussion, which in turn enhanced their understanding of coursework material. The instant access from classroom to construction site was considered a positive, as was the capacity to revisit the site and follow aspects of the construction process independently. Suggestions for improvement in the Usability Trial included more defined learning tasks with clearer aims and links to assessment. A guided tour was suggested, and giving more detailed whole-of-class explanations of construction processes and building elements as students using the 4D environment discover them. Respondents in the Pilot Study found the site to be a useful interactive visual aid that enhanced their comprehension, while the capacity to view 2D and 3D information together enhanced their understanding.

**Question 5 Improvements**

Question 5 was an open-ended question that prompted students to offer suggestions for future improvement. Suggestions from both the Usability Trial and the Pilot Study trials included developing the 4D environment for use on a mobile tablet and providing additional building case studies of various scale and complexity. Students commonly requested using consistent node positions on each floor and across each survey and including call-out labels to explain key construction processes and building elements.
Comparison across programs and year levels

An objective of the project was to develop a flexible 4D environment that could be applied across different professional programs and year levels. Table 2-2 summarizes the student evaluation results from the 2014 Usability Trial of the 4D environment Version 2 with Year 3 Bachelor of Architecture students at UQ and compares the results with those of the 2015 Pilot Study trials of Versions 3 and 3.1 at UQ, UoN and UniSA.

Table 2-2: Comparison of 2014 and 2015 student evaluation results

<table>
<thead>
<tr>
<th>Year and program</th>
<th>Evaluation questions (% agree or strongly agree)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. Did you like the appearance of the learning environment?</td>
</tr>
<tr>
<td>Semester 2 2014 – 4D Construction Learning Environment Version 2</td>
<td>76%</td>
</tr>
<tr>
<td>Year 3, Bachelor of Architectural Design n=59</td>
<td>96%</td>
</tr>
<tr>
<td>Semester 1 2015 – 4D Construction Learning Environment Version 3</td>
<td>85%</td>
</tr>
<tr>
<td>Year 3, Bachelor of Construction Management n=39</td>
<td>83%</td>
</tr>
<tr>
<td>Year 1, Bachelor of Construction Management n=63</td>
<td>95%</td>
</tr>
<tr>
<td>Year 2, Bachelor of Engineering n=119</td>
<td>97%</td>
</tr>
</tbody>
</table>

The comparison demonstrates a general alignment of outcomes for the three versions with some notable exceptions. Significant effort was made to address reported issues with the appearance and functionality of Version 2. This is reflected in an improvement in responses to appearance (Question 1) and navigation (Question 2) from Version 2 to Version 3. A further variation was detected between year levels. Responses suggested that the student learning experience in earlier years would be improved if the students became familiar with elementary technical terminology and construction processes.
3. **Project outputs and findings**

3.1 **Summary of project deliverables and outcomes**
The following deliverables were achieved over the course of the project:

- a 4D digital learning environment that captures construction of UQ’s AEB over time
- enhancement of the 4D environment by embedding construction documentation (digital drawings), contract administration items (minutes of meetings, requests for information, architects’ instructions, contract sum adjustments, adjustments of time), time-lapse videos, and interviews with key members of the AEB design and construction project team
- the design of innovative interdisciplinary curricula and integrated problem-based learning activities that enhance the student learning experience through the realistic simulation of workplace learning
- the iterative evaluation of the impact on teaching practice for academic staff to allow progressive adjustment of the 4D environment
- a sound technical, pedagogical and professional foundation for a future library of construction projects
- four refereed conference papers (refer to Section 3.2), one conference poster presentation and a number of seminar presentations (refer to Section 4.2).

3.2 **Publications**
The project team used conference presentations to communicate the work in progress. A further two journal publications are planned on completion of the project. The four peer-reviewed conference papers published to date are:


The first paper, presented at the 2015 Higher Education Research and Development Society of Australasia conference, reported on the development of the initial 4D environment prototype, and the initial Usability Trial student evaluation.

The second paper was presented at the 2015 International Conference on Advances in Management Science and Engineering, an international forum for engineering education. The paper provided preliminary reports on the Pilot Study deployment of Version 3 of the 4D environment, and reflections on curriculum development, user experiences and educational effectiveness.

The third paper was presented at the 2015 Association of Architecture Schools of Australasia conference. This paper reported on the first use of the 4D environment in core coursework. It also provided an analysis of student feedback with regards to its usability, engagement and effectiveness.

The fourth paper was presented at the Australasian Architectural Science Association annual conference. This paper focused on the use of the 4D environment, from a self-directed learning resource to an immersive learning environment, across four different disciplines and seven courses.

### 3.3 Project success factors

The 4D environment provides a realistic context for simulated problems that activate student learning because it uses a collaborative problem-based approach to enhance critical thinking skills. Resources developed over the course of the project are described in Section 3.1 available through the 4D environment project website at:

- http://4dconstruction.architecture.uq.edu.au/home

As mentioned in Section 1.2, the project is indebted to an earlier OLT-funded 3D digital learning environment for process engineers developed by Professor Ian Cameron and others (Cameron et al. 2009). The project has also responded to literature in the field, which suggested that work-integrated learning through simulated real-life contexts had a capacity to enhance the critical thinking skills and work-readiness of students.

The project involved the development and application of the 4D environment across institutions (architecture at UQ and UniSA) and disciplines (architecture, construction management and engineering). Ultimately, the 4D environment has provided a flexible and
robust means to enhance these institutional and professional linkages with promises for further dissemination in the construction industry and related fields.

While the cross-institutional and interdisciplinary nature of the project was vital to the success of the project in terms of the breadth and flexibility of outcomes, it was a factor that contributed to the consistency and depth of the final outputs. A significant factor in the success of the project was the role of a professional project manager. Without a dedicated and skilled person in this role the project focus would have wavered and the project milestones would not have been met. The project evolved over the two-year period. During this time, some aspects of the initial project proposal were deleted, such as the scenario development workshops with industry, and replaced with the development of case study specific interviews and course-specific learning activities and assessment strategies. This greatly enhanced the final project outcome, which now stands as a flexible and sustainable resource that can be adapted to a variety of discipline and year level contexts.

Finally, the project provides a self-contained and flexible platform for curriculum development across construction-related disciplines, programs and year levels. However, links could be made to further research in several key areas:

- the impact of the 4D environment on assessment and student learning
- curriculum design to take best advantage of the 4D environment
- the impact of the 4D environment on the development of student employability skills and work-readiness.
4. Project impact, dissemination and evaluation

4.1 Project impact

The project has impacted upon the following stakeholders: course coordinators responsible for designing and implementing specific learning activities and assessing their effectiveness; program convenors responsible for designing and managing program compliance with university and professional accreditation requirements; students; and industry stakeholders including employers and professional accreditation bodies.

Each project team member is responsible for coordinating one or more courses at their home institution, into which the 4D environment has been, to a greater or lesser extent, integrated in order to facilitate learning and assessment activities.

The degree of student-centredness has varied from course to course in response to the specificities that each imposes. This has resulted in the tool being used a range of ways, from a highly directed fashion as a teaching aid through to varying degrees of student autonomy where the learner is free to explore both the 4D environment and the related documentary content at will in order to devise an appropriate response to the learning challenge.

A number of the project team members are also responsible for maintaining the integrity of the programs that they manage. For them the challenge is not only to ensure the integrity of learning activities and assessment strategies in terms of meeting course objectives. They also need to ensure that the introduction of innovative teaching approaches does not threaten the program integrity in terms of meeting internal university teaching and learning quality standards, and the requirements of professional accreditation bodies.

For example, Australian architecture programs are accredited against the National Standard of Competency for Architects (NSCA) (AACA 2015). The NSCA identifies 37 Performance Criteria across four Units of Competency that must be attained by graduates for accreditation purposes. If students use the full array of 4D environment resources they would enhance the development of a number of competencies across the four Units of Competency (Design, Documentation, Project Delivery and Practice Management).

For example, Design Performance Criteria 4.5 Investigation and integration of appropriate structural, construction, service and transport systems in the project design; Documentation Performance Criteria 5.3 Evaluation and integration of regulatory requirements; Project Delivery Performance Criteria 7.1 Identification of available procurement methods and assessment of relevance and application to the project; and Practice Management Performance Criteria 9.8 Clear and consistent communication with client and relevant stakeholders throughout project.
The students themselves have been impacted – generally in a positive fashion, as it turns out – by the introduction of the 4D environment and the accompanying innovative teaching approaches. These approaches have set out to challenge students to engage in learning activities within contexts that more closely replicate industry conditions and real-life project settings.

Student evaluation collected from multiple courses in diverse programs across three institutions indicates that the 4D environment positively assisted their understanding (79 per cent of respondents) and enhanced their learning experience (73 per cent of respondents) (refer to Section 2.3).

It is reasonable to suggest that this assisted understanding and enhanced learning takes place alongside the learning of new skills needed to navigate the 4D environment and explore the range of possibilities that it presents. This potentially increases the workload requirement for a particular learning activity, but is presumably offset by the benefits that the 4D environment presents (as can be seen in positive student feedback).

Industry input and feedback on the project has largely taken the form of individual submissions to the advisory panel, though industry practitioners and representatives of professional institutes have all commented favourably upon the functionality of the 4D environment and suggested practical applications for its use within their own business organisations and professional bodies. The real impact of this project on their businesses will only be felt in the coming months and years, as graduates who have been exposed to the 4D environment engage in their professional lives. These graduates will, ideally, display enhanced levels of understanding and performance when confronted with on-site challenges. However, assessment of the impact of the 4D environment on the development of critical thinking skills and work-readiness needs further targeted investigation.

There is a further group that has the potential to be affected by this project, namely fellow academics in faculties and institutions not directly affiliated with the project. To date this impact has been confined to the dissemination of interim project findings through refereed conference papers (refer to Section 3) and internal workshops. A post-project dissemination strategy has been developed to promote the 4D environment to academic and industry stakeholders in the coming months and further journal articles are planned.

### 4.2 Project dissemination

In addition to the conference papers listed in Section 3, other dissemination activities that have been undertaken to date include:

- Landorf, C. (2014). Presentation of the 4D Construction Learning Environment Version 2 to the AEB design and construction project team. 22 July 2014. This session produced feedback as to how the 4D environment might be further developed and deployed within the scope of the existing project, as well as more widely.


• Brewer, G. (2016). ‘Designing learning events for construction management curriculum utilising 4D learning environments’. Paper pending for the 40th Australasian Universities Building Education Association 2016 conference, 6–9 July 2016. Cairns, Australia. Graham Brewer has also been invited to give a conference keynote address on radical innovation in construction, which will include the need for, and impact of, educational experiences that mirror the complexity and technocentricity of 21st century construction.

Further post-project dissemination activities include planned meetings with the various professional bodies represented by the project team members, with a view to showcasing both the technology and the learning potential it provides. Opportunities exist through the professional bodies to both disseminate information about the 4D environment to their membership and incorporate the use of the 4D environment into their continuing
professional development programs. By way of example, learning and assessment activities can be readily facilitated that will enable building surveyors to adapt to changes in the National Construction Code such that participants can demonstrate their correct understanding and interpretation of code changes in real-world situations.

### 4.3 Project evaluation

The project has been subject to seven evaluation events that have led to reflection on and subsequent modification of either the project approach or the 4D Construction Learning Environment. The evaluation events have occurred as a consequence of the involvement of the Project Evaluator, the Project Advisory Group or after a deployment of the 4D environment with students. Evaluation events occurred as follows:

- July 2014 project team meeting – Project Evaluator feedback on Version 2
- Semester 2 2014 Usability Trial – student evaluation of 4D environment Version 2
- January 2015 project team meeting – Project Evaluator feedback on Version 3
- Semester 1 2015 Pilot Study – student evaluation of 4D environment Version 3
- July 2015 project team meeting – Project Evaluator feedback on Version 3
- Semester 2 2015 Pilot Study – student evaluation of 4D environment Version 3
- Semester 2 2015 Project Advisory Group meeting – Project Advisory Group feedback on Version 3
- January 2016 final project evaluator report (Appendix B).

The evaluation/reflection/modification cycle outlined in Section 2.2 Research methodology, and the events detailed above, have resulted in incremental improvement in both the functionality of the 4D environment and the design of the various learning activities that have been trialled over the course of the project. The positive impact of evaluation on development of the functionality of the 4D environment and associated curriculum design is reflected in comparisons of the student evaluations for Version 2 of the 4D environment, conducted in Semester 2 2014, and Version 3, conducted in Semesters 1 and 2 of 2015 (refer to Section 2.3 and Table 2-2).
5. Discussion and conclusions

Work-integrated learning, as a means to achieve a balance between theory and practice, is a topical feature of higher education. While work experience has had a long tradition, particularly in professional education, the pressure of student numbers and need for pedagogical rigour have impacted on the opportunities available for students to spend time in workplace settings that are relevant to their degrees. In construction-related professions, workplace health and safety concerns have an additional impact on students’ access to ‘live’ building sites.

Within this context, opportunities exist to explore alternative ways of providing the benefits of work-integrated learning by simulating real-life contexts. Although studies have explored computer-simulated virtual reality environments, none have focused on the development of a 4D digital learning environment based on a ‘live’ construction project. The project detailed in this report provides such an environment.

The 4D Construction Learning Environment has been well received by academics and students in four different programs at three institutions. For academics, the possibilities offered by the 4D environment range from its use as a simple demonstration tool suitable for use in a conventional on-campus lecture through to a comprehensive, immersive, problem-based learning scenario and assessment system requiring engagement with the full array of resources offered within the environment (4D images, drawings, contract documents, time-lapse videos and interviews). The 4D environment has also been shown to be an effective tool across different disciplines and year levels.

For students, the project evaluation evidence indicates that the 4D environment can be used effectively within existing course aims and professional accreditation structures to improve learning outcomes. The 4D environment was found to enhance students’ understanding of construction processes, and to give them a means to learn collaboratively and contextualise theoretical material.

It is apparent, however, that using the 4D environment as a simple visual aid represents a shallow engagement with the pedagogical possibilities that it offers. While there are issues, such as the dependence on predetermined survey nodes and the consistency of node locations from survey to survey, the 4D environment can provide a genuine, flexible and cost-effective improvement over traditional lecture-tutorial activities, but only when it is fully utilised and holistically integrated into the curriculum.

‘Virtual’ work-integrated learning has the potential to satisfy, at least in part, student and employer demand for a balance between theory and practice, as well as to provide work-ready graduates who have the capacity to engage immediately in their chosen professional settings. The benefits are, however, contingent upon the skilful integration of immersive learning scenarios into those parts of the curriculum where their full benefit can be realised.
This project provides one building case study, the AEB; however, it is important to note that the 4D Construction Learning Environment could host additional case studies of different building types and scales. The 4D environment could also host additional self-directed and discipline-specific tutorials with pop-up text boxes to explain elementary technical terminology and construction processes. Together with further dissemination activities, such a development of the 4D environment would enhance the adoption of the resource across disciplines, programs and year levels.

**Future directions**

Finally, this project has identified four associated areas that warrant further exploration:

- The project has shown that the 4D environment has the capacity to enhance and contextualise student learning; however, its impact on the development of critical thinking skills and work-readiness needs further, targeted investigation.

- The project has led to the design of a variety of innovative learning activities and assessment strategies that enable the integration of the 4D environment across different disciplines and year levels. There is significant scope to develop and evaluate additional creative teaching approaches.

- The application of new 3D laser scanning technology and advances in virtual reality software are areas of growing interest within the construction industry, as well as allied areas such as archaeology, heritage management and town planning. There is an opportunity to investigate the integration of this technology and software into further iterations of the 4D environment.

- The 4D environment currently hosts one case study of a complex educational building type, the AEB at UQ. There is an opportunity to enhance the adoption and impact of the 4D environment through the inclusion of additional case studies of different building types, scales and geographical locations.


Royal Commission into the Building and Construction Industry (RCBCI) (2002). Overview of the nature and operation of the building and construction industry. Canberra: AGPS.


Appendix A

Certification by Deputy Vice-Chancellor (or equivalent)

I certify that all parts of the final report for this OLT grant/fellowship (remove as appropriate) provide an accurate representation of the implementation, impact and findings of the project, and that the report is of publishable quality.

Name: ............Professor Joanne Wright...........................................

Date: 11/02/2016............
Appendix B

Project Evaluator’s report
Independent project evaluation

Developing a 4-dimensional interdisciplinary learning environment for construction industry professionals

Conducted by Professor Stephen Loo, University of Tasmania

on behalf of the Australian Government Office for Learning and Teaching (OLT) at the request of The University of Queensland

January 2015

Contents:

1. Executive summary
2. Project evaluation framework and methodology
3. Project evaluation matrix
4. Evaluation of project outcomes
5. Evaluation of project impact
1. Executive summary

The 4-dimensional (4D) Construction Learning Environment project is based on a complex architectural and construction project, namely the Advanced Engineering Building (AEB) at The University of Queensland (UQ). There is compelling evidence that the project makes a significant contribution to student learning and has gained research advances in teaching methods and curriculum development. The independent evaluation of this project indicates that the outcomes of the project were substantially met, and the relevant professions, industries and university programs stand to gain from this highly relevant and well executed and managed project.

The 4D Construction Learning Environment project is a much-needed and effective departure from conventional teaching and learning approaches in the built environment disciplines, where it can be difficult to integrate real construction project information and provide visual evidence of events on site, including actual decisions about the design and building, and contextual information related to the design intent, contractual obligations and project administration.

The project is a challenging one because it integrates ‘analogue’ technology for static panoramic photography into a new immersive technology platform. It provides students with simulations of real construction projects, so they can develop critical faculties in theory–practice relationships through workplace-integrated learning. Importantly, it allows the students to integrate knowledge from documentation sources in different professional domains – drawings, reports, site minutes, video interviews and stop-motion movies – when they see views of the construction that are framed in space and time.

Student evaluations of the project demonstrate consistent positive feedback and that the 4D environment had a high impact, which assisted in their learning. The student feedback (both positive and negative) assisted in fine-tuning the design of both the 4D environment and the curriculum. An important, positive outcome of this project was greater collaboration between team members across three different institutions and four different disciplines.

The test of the longer-term impact of the project will be: how widely it is adopted, how it influences curriculum design in different institutions in the region, and whether it contributes in some way to the assessment of architecture programs. This contribution could be to accreditation (assessed by the profession) or to quality (assessed by the government).
2. Project evaluation framework and methodology

The purpose of the independent evaluation is to assess whether the project’s outcomes achieved the stated aims and objectives.

This report evaluates:

- **Outcomes** that is, the usability of the 4D environment – user interface and graphic design, scenario design, development of learning activities/curriculum
- **Impact** of the 4D environment for the team, students, institutions and the profession and industry.

**Evaluation framework and criteria**

The evaluation strategy is focused on three broad levels:

1. The processes used to achieve the final project outcomes.
2. The usability issues associated with the 4D environment.
3. The educational impact of scenario-based learning activities that use the 4D environment.

The project was evaluated at the three levels of evaluation strategy – Levels 1 and 2 on **Outcomes**, and Level 3 on **Impact** – which were mapped onto six intended project outcomes as proposed in the aims of the project:

**Level 1: The processes used to achieve the final project outcomes**

*Outcome 1.1:* A 4-dimensional digital learning environment that captures construction of UQ’s AEB over time.

*Outcome 1.2:* The design of innovative cross-disciplinary curriculum and integrated problem-based learning activities that enhance the student learning experience through the realistic simulation of workplace learning.

**Level 2: The usability issues associated with the 4D environment outcomes**

*Outcome 2.1:* Enhancement of that learning environment through the embedding of construction documentation, contract administration items and interviews with the construction professions.

*Outcome 2.2:* A sound technical, pedagogical and professional integrated foundation for a future library of construction projects.

**Level 3: The educational impact of the scenario-based learning activities**

*Outcome 3.1:* Impact on learning outcomes for construction industry students, and iterative evaluation to allow progressive adjustment of the learning environment.

*Outcome 3.2:* Impact on teaching practice for academic staff, and iterative evaluation to allow progressive adjustment of the learning environment.
The evaluation also considered five cross-cutting criteria based on key elements of successful projects:

- effective project leadership and strong project management
- sustained and effective project team member contributions with adequate institutional support
- clear goals and shared understanding of the project’s desired outcomes and the processes
- effective dissemination strategy of outcomes and findings
- plan for achieving impact, and key relationships to facilitate impact.

**Evaluation methodology**

It was agreed at commencement of the project that the independent evaluation of the project would consist of:

- an interim evaluation report to be completed in January 2015. The evaluation of the project towards the interim report was carried out during the face-to-face project meeting at the end of Year 1
- a final evaluation report to be completed in January 2016, alongside the final project report at the project’s conclusion. The evaluation of the project for the final evaluation report was carried out in the period between the final face-to-face project meeting at the end of Year 2 (November 2015) and January 2016
- progressive mentoring and feedback throughout the project by the independent Project Evaluator, through participation in as many teleconference and face-to-face meetings as practicable. In the first year (2014), the feedback, mentoring and independent evaluation generally focused on the construction, functionality and deployment of the 4D environment; in the second year (2015), the focus was generally on curriculum development and scenario design using the 4D environment, and its integration into various university courses and programs; and in the third year (2016), the focus was generally on gathering and interpreting student evaluation data, and feedback from the advisory panel.

The project evaluation was based on the following data and information:

- review of all documentation related to the project
- student and staff evaluations of the 4D Construction Learning Environment
- discussions at interim teleconference meetings and observations at face-to-face meetings in November
- review of student and academic staff evaluations of the functionality and quality of the 4D environment, and scenario-based learning activities and curriculum design
- discussions with members of the project team, including the team leader and project manager
- discussion with the project Advisory Group based on the evaluation matrix.
The Project Evaluator evaluated the project in relation to the processes (methods and measures) set in place to achieve its stated outcomes and aims and whether the project was implemented as proposed and within timelines.

The Project Evaluator assessed the responses of the project team and their students to usability issues of the 4D environment, and drew limited conclusions about its wider usability because the scope of the project was governed by scenarios provided by participating project partner institutions within the short timeframe of the project.

Similarly, the project evaluator drew conclusions about the impact of the project’s scenario-based learning from observations made during the activities by participating project partner institutions within the timeframe of the project, and by seeking informed perceptions from the project team members and project Advisory Group. The information gathered from the project team members arose from ongoing discussions throughout the project, based roughly on an evaluation matrix. Originally, quantitative analysis was intended but it did not occur. The Project Advisory Group had one formal meeting during the project. The independent evaluation was carried out using the feedback from that meeting, so the conclusions are limited to that information.

These perceptions and the findings will be useful, but it will take a further two to three years with a more extensive evaluation framework and more research to gauge the wider usability and educational impact of the 4D environment for relevant stakeholders, such as curriculum leaders, teachers, students, employers and the professional bodies. This is especially important if a library of buildings is to be created and the 4D environment is to be used for other courses and by other institutions.
### 3. Project evaluation matrix

The evaluation uses a matrix as a framework to collate the extent of outcomes and impacts. This matrix is the lens through which the independent evaluation was carried out during the project:

<table>
<thead>
<tr>
<th>Level 1: Processes used for outcomes</th>
<th>Rating of importance of cross-cutting factor to outcome and extent of achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Leadership and management</td>
</tr>
<tr>
<td>1.1: A 4-dimensional digital learning environment that captures construction of the University of Queensland’s (UQ) Advanced Engineering Building (AEB) over time</td>
<td></td>
</tr>
<tr>
<td>1.2: The design of innovative cross-disciplinary curriculum and integrated problem-based learning activities that enhance the student learning experience through the realistic simulation of workplace learning</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level 2: Usability issues with the 4D environment outcomes</th>
<th>Rating of importance of cross-cutting factor to outcome and extent of achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1: Enhancement of that learning environment through the embedding of construction documentation, contract administration items and interviews with the construction professions</td>
<td></td>
</tr>
<tr>
<td>2.2: A sound technical, pedagogical and professional integrated foundation for a future library of construction projects</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level 3: The educational impact of the scenario based learning activities.</th>
<th>Rating of importance of cross-cutting factor to outcome and extent of achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1: Impact on learning outcomes for construction industry students, and iterative evaluation to allow progressive adjustment of the learning environment</td>
<td></td>
</tr>
<tr>
<td>3.2: Impact on teaching practice for academic staff, and iterative evaluation of to allow progressive adjustment of the learning environment</td>
<td></td>
</tr>
</tbody>
</table>
4. Evaluation of project outcomes

This section includes evaluation of each of the four project outcomes in Levels 1 and 2. Evaluation of each outcome also includes commentary through the five cross-cutting criteria.

**Outcome 1.1:** A 4-dimensional digital learning environment that captures construction of The University of Queensland’s (UQ) Advanced Engineering Building (AEB) over time.

Evaluation

The project has successfully achieved its aim to construct a learning environment for the architecture and building disciplines on an interactive digital web-based platform. The project uses spatially located and coordinated 3-dimensional (3D) photographic images of The University of Queensland’s (UQ) Advanced Engineering Building (AEB), which were collated over time and embedded in a single-user application prototype from a prior UQ Teaching and Learning Strategic project. This project reconfigured the existing static imaged-based data, including its spatio-temporal dimensions and construction sequence information – hence a ‘4D environment’ – into a multi-user, accessible, interactive app-based product.

The aim was to make the building project information of a real construction project available to students, primarily through visual evidence of events on site and drawn documentation of actual design and building decisions, supplemented by contextual information on design intent, contractual obligations and project administration.

At the early stages, the project met with difficulties in enhancing user interactivity and experience, because the existing data was made up of static single-frame photographs taken from locatable viewpoints across identified points in time and stitched together in panoramas. However, the students and academics expected that a contemporary app-based digital interface would be a seamless navigable virtual (game) space with drop-down, pull-down or drop-in information menus. As a consequence, much time in the first year was spent in coding, scripting, and designing the interface to make the capabilities of the 4D environment (governed by the limitations of static image data and ‘older’ Flash-based technologies) more self-evident during interaction. A major conversion occurred halfway through the project when coding was converted to HTML5 to increase operational flexibility in other devices.

The final outcome successfully balances the pedagogical aims of the 4D Construction Learning Environment with the available and sourced data within the timeframe of the project. The viewpoints of building construction are fixed, and information density is focused on three separate views – auditorium, atrium and terracotta façade – correlated with the problem-based learning scenarios identified (see 1.2), augmented with plans and other support documentation and
supplemented with other media (prerecorded interviews with design and construction team members, etc.).

Commentary on cross-cutting criteria

The design and construction of the 4D environment required management of complex negotiations between multi-modal information such as static imagery, analogue documents and digital space interactivity, which are not often compatible, the expectations of students and other users in a contemporary academic space, and fast-changing software and hardware capabilities. This project outcome benefitted from access to the image data, technology and team members from a previous seed project. Through good leadership, the team leader and project manager maintained the pedagogical focus and the shared goals of the team in order to drive the technological work (that is, developing a lean and efficient 4D environment using the limited time, data and resources available), so the project has been able to avoid developing the digital interface and engine at the expense of good learning and teaching outcomes. The project manager’s role in organising and managing the technical team, image and document producers and software developers is commendable. The project manager managed the flow of information so the technological development information did not overburden the academic team, and the pedagogical requests/requirements were successfully communicated back to the technical team. The technical prototyping, development and trial of the 4D environment have been published as refereed papers at significant conferences, namely the Higher Education Research and Development Society of Australasia (HERDSA) and the International Conference on Advances in Management Science and Engineering (AMSE).

Outcome 1.2: The design of innovative cross-disciplinary curriculum and integrated problem-based learning activities that enhance the student learning experience through the realistic simulation of workplace learning.

Evaluation

A key aim of the project is to foster cross-disciplinary collaboration and interaction between related disciplines in architecture and construction through project-based learning, which is clearly necessary in the professional real world, but is often underplayed or absent within academia because of distinct disciplinary and faculty boundaries. More important is the coordination of information between various components of building procurement – design, documentation, contract administration, construction, regulations and costing – as the building progresses on site.

The project achieves this outcome through the design of problem-based learning scenarios that can become a part of curricula in various courses and can foster
interaction between cross-disciplinary courses. Scenarios based on complex multi-dimensional problems or spaces that are complicated to build, involving high-level coordination, are turned into questions for the students as a small or significant part of their coursework. In some cases the 4D environment is used as an available resource to facilitate other learning outcomes.

Through the development of learning scenarios, the project successfully implemented the use of the 4D environment in eight different courses in four different disciplines at three universities. The identification of learning scenarios and the design of cross-disciplinary curriculum served two aims. First, the scenarios informed the technical development of the 4D environment itself, providing interconnections between data, information and construction in progress that occur in reality, and which tested the fidelity of information interactions that can occur in the environment. Second, the scenarios allow new relations between various disciplines and associated information/experience to be generated, thereby innovating collaborations through workplace-integrated learning.

Commentary on cross-cutting criteria

The cohesive nature of the research team, which was made up of academics from different disciplines, was a major factor in successfully identifying the learning scenarios and incorporating them into the respective curriculum designs. All team members demonstrated creativity in shaping the 4D environment design to suit pedagogical aims and to realise the potential in the nature of the data and the possibilities of the immersive experience to influence their curriculum design. There was significant understanding of the limitations in designing university courses (having to subscribe to different university-sanctioned learning outcomes, timetable and program structures and assessment requirements and to deal with diverse student evaluation procedures). There was evidence of institutional support from all partner universities, through team members, to allow the incorporation of the 4D environment into curricula. The team has an appropriate balance of skills, interest, expertise and experience to balance their respective pedagogical strategies and the unknowns of the 4D environment as it was developed. The team’s efforts to gain student evaluation and feedback data in all courses are to be commended. Survey participation rates are significant and the data obtained is invaluable to assess the impact of the project outcomes (see 3.1).

The team leader’s interdisciplinary experience, which crosses design, construction and professional studies, was very important and greatly assisted in the translating of the learning and teaching concepts across disciplines and the management of a diverse project team. Project team members possessed the flexibility and demonstrated the creativity in thinking needed to find ways to integrate the 4D environment into the curriculum at each partner institution. As a result, the applicability of the tool was increased, innovative changes were made to the design of the 4D environment and its functionality was improved.
Outcome 2.1: Enhancement of that learning environment through the embedding of construction documentation, contract administration items and interviews with the construction professions.

Evaluation

The project successfully achieved something that has been deeply missed in many university architecture and building programs: a platform for students and academics to work across a range of documentation with diverse modalities (drawn, written, visual and oral), underpinned by epistemologies of different disciplines. The gaps between documentation cause major issues of miscommunication and misunderstanding, which have a high economic impact on design and building procurement.

The 4D environment finds a way to include, and to give immediate real-time access to, relevant documentation within an immersive learning environment. This helps break down professional barriers, develops an understanding of different disciplines, and opens dialogue between students in the same course as well as across disciplines. Both consistencies and inconsistencies in documentation, for example, in design drawings, technical documentation, specifications, site minutes and visual observation (real scenarios recorded in images which are spatially and temporally navigable), allowed students to interact and critically engage with the design and construction processes, which have a high fidelity to real-life scenarios. The project is an excellent example of work-integrated learning carried out within current class sizes and educational infrastructure, which generally prohibit site-visits. The project, uniquely, simulates real-world scenarios, so it opens up potential connections and new avenues of collaboration and research connections between academics of different disciplines.

Commentary on cross-cutting criteria

The role of project manager was key to the success of this component. The project manager very efficiently and successfully sourced and chased up information, dealt with different file types, including videos and movies, and incorporated this material into the 4D environment. The project manager was open to continued suggestions and changes required by project team members to make the 4D environment tool relevant to their courses, and to the difficulties of integrating the different file formats into the digital design of the environment. Project team members received support from their individual institutions and stakeholders within their respective projects (contractors, designers, consultants etc.) to provide the relevant documentation. This established a data- and information-rich learning environment, which facilitated connections between different components of the project. At the same time, the history of the building project was opened to new scrutiny and different conclusions.
Outcome 2.2: A sound technical, pedagogical and professional integrated foundation for a future library of construction projects.

Evaluation

Because it has a relatively simple image-based data platform, the 4D environment can be replicated using other projects, across scales. The AEB is a complex building; therefore, the tool is easily adaptable for smaller projects, including those of a domestic scale. Translating the project across different building scales is challenging – it will be more straightforward with smaller construction – but the benefits are large because the platform has the potential to take the place of site visits, especially in the early years of courses.

Although the developments in this project can be replicated, very particular photography, surveys and documentation will be needed in order to populate the 4D environment platform. This includes early notice of available projects, agreement from a client and building contractor for the particular set-up of time-lapse cameras from the start to the finish of construction, access to a range of relevant building documentation, and building professionals willing to participate in interviews etc.

This process is ‘analogue’, so it can be replicated. However, there are new technologies out now (video and 3D scanning etc.), that will make the design of the app and interface far more fluid and navigable, so this means rethinking the digital platform of the learning environment. The 4D environment is currently a post-construction learning and teaching platform. It is possible that the platform can be modified to have access to the site while the construction process is ongoing, but this has both practical and legal implications.

Commentary on cross-cutting criteria

Translating the project to other buildings and compiling a library of other projects would rely heavily on shared aims within the project team, and a common understanding of the conceptual ideas and possible practical outcomes of the project. There are many other ways this platform can be designed and these options are growing fast with newly available technologies. The translatability of the project requires a clear ‘Guidelines’ document which outlines the requirements of the project, its limitations and, more importantly, its benefits. The project is based on a strong mixed-media platform (a combination of old ‘analogue’ technologies and new app-based interactive technologies), which has a degree of resilience to the ever-changing landscape of digital technologies. If the project is to prove its worth, it will need to be applied and disseminated well and consistently in the near future, especially its pedagogical approach, which relies on more static, considered and ‘curated’ images. Its design and the nature of the technology mean it could, potentially, be dismissed easily as less effective, less immersive and less interactive than other options, although these other options are not yet widely available for teaching and learning use in construction-related disciplines.
5. Evaluation of project impact

This section pulls out key findings on assessment of the project's impact from the project evaluation matrix, namely:

**Outcome 3.1:** Impact on learning outcomes for construction industry students, and iterative evaluation to allow progressive adjustment of the learning environment.

and

**Outcome 3.2:** Impact on teaching practice for academic staff, and iterative evaluation to allow progressive adjustment of the learning environment.

Impact is defined as 'the difference that a project makes in its sphere of influence, both during and after the funding period' (Hinton, IMPEL, 2014).

The evaluation of the impact of the project will comment on the impact plan, the appropriate level of positive and substantial changes, and the benefits and value for students, staff, institutions and the higher education sector. This section will also comment on the strengths of the dissemination strategy, the Project Team’s ability to bring about the identified outcomes and planned impact, and an outline of the key relationships that facilitated that impact.

The impact evaluation is organised using the IMPEL stages or extent of change achieved:

**Team members**

The project allowed team members from different disciplines to work together on common issues, which improved both shared understanding of the multi-faceted industry and cross-disciplinary awareness. The 4D environment made research collaboration possible across courses, programs and institutions, because it generated new research questions that had previously been unavailable and fostered partnerships.

The project has a direct impact on the teaching capacity of team members. It enhances the quality of teaching by team members because it is an available tool that can be used either centrally within a course they are teaching or as a self-help resource for students. Increased student satisfaction, as measured by official student evaluation processes, and augmented by a clear pedagogical concept and approach, enhances the academic standing of team members and their cases for promotion. The project also directly affects cases for promotion through the increased number of interdisciplinary co-authored refereed conference papers and journal articles, invitations to speak, and increased professionally relevant community engagement. The project can be used to increase opportunities for service and leadership, especially in the teaching and learning space.
Developing a 4-dimensional interdisciplinary learning environment for construction industry professionals

The team leader and other members of the team demonstrated and, supported by the project manager, maintained the longer-term vision for the project. The team demonstrated a deep understanding of the impact of such a tool in learning and teaching in architecture and construction. The project team had connections to professionals from different areas of the design and construction industry, and several influential members were part of the project Advisory Group, so the project Team was keen to make sure the project was sustainable and viable in the longer term. The documentation of the design, construction and testing of the 4D Construction Learning Environment tool was thorough, so future academics and learning and teaching situations may be able to continue to use and develop the 4D environment.

Immediate students

Overall the data summarised from student evaluations across five different courses in three institutions indicate general agreement that the ‘appearance’ and ‘ease of use’ of the 4D Construction Learning Environment is positive (91 per cent agreed or strongly agreed for ‘appearance’ and 80 per cent for ‘use’). The tool was tested throughout the early phases of development by students and members of the project team who provided feedback about its interface design and interactivity. The project evaluator also provided feedback during this process. Many of the suggestions about functionality and appearance were accepted and successfully integrated into the design of the 4D environment, which resulted in the positive outcome in the student evaluation trials data.

Students were asked whether the 4D Construction Learning Environment and its associated learning activities ‘assisted students’ understanding of course content’. Again the level of agreement was high (79 per cent agreed or strongly agreed). Because the 4D environment tool can be applied across multiple disciplines, it is harder to glean how well and how broadly students understood the content of specific courses, from the student evaluation data. In the written feedback, students very often mentioned that because they could see images of construction in progress and compare them to documentation drawings or construction management course content, they gained a greater insight into the ways professions are coordinated during the procurement of buildings.

The 4D Construction Learning Environment seems to have ‘enhanced [students’] learning experience and skill development’ (73 per cent agreed or strongly agreed). The written feedback, from those students who made comments on this question, did not clearly indicate how the 4D environment has enhanced learning. It is possible that students still find the modes of learning relatively novel, and that the effects on their learning will only be evident after more widespread, iterative use of the tool and greater cross-disciplinary collaboration.

The 4D Construction Learning Environment is now available as an innovative and novel teaching tool that can be used either centrally within a course or as a resource.
for students to use independently. It develops students’ cross-disciplinary understanding of professions involved in the procurement of buildings, and how the documentation interacts, based on an interactive visual survey of construction images.

**Spreading the word**

The project has a good communications plan and has achieved consistent dissemination of progress, products and findings across all stages of the project. Various team members communicated project findings and outputs through refereed conference presentations and papers. There were also more local presentations internal to the institutions at appropriate learning and teaching events.

Design and construction of the prototype of the 4D Construction Learning Environment was presented at HERDSA, a long-standing, internationally significant conference on higher education research and development in Australia. HERDSA’s reach is large and it is the premier avenue for disseminating new research on higher education.

The deployment of the tool and feedback on user experience and curriculum development was presented at the AMSE. Dissemination of this architectural construction-based project would have reached a diverse audience because AMSE is a cross-disciplinary conference focused technically on manufacturing/engineering.

Papers have also been published in AASA and ASA, the two key international conferences on architectural education research and architectural science research, respectively, run by Australian institutions (top quartile conferences in FoR12 ERA 2015). Work on the integration of the 4D Construction Learning Environment into curriculum development across different courses in various disciplines would have again reached a wide Australian and international audience through these two conferences.

Effective and consistent dissemination of the project and its development needs to continue so that the efforts and findings do not become obsolete in this time of fast-changing technology. The requirement to publish guidelines for the construction and use of the 4D environment, as the Project Advisory Group, is paramount.

**Narrow opportunistic**

Students have the opportunity to experience important vocational training (or workplace-integrated learning) within their university-based courses. From student evaluation surveys, the 4D environment has effectively provided students with an insight into the complexity of roles, responsibilities and interactions between professions in the building industry, and has provided critical armature to reflect on theory–practice relationships.

The project is a typical of one that relies on teamwork. Students and academic staff have had the opportunity to work together in order to use the 4D environment,
whether in simple tasks like navigating the site or more complex activities such as coordinating and interpreting the information or undertaking critical reflection.

Narrow systemic
For now, the project has influence only within the architecture and construction disciplines within the participating institutions. The pedagogical and professional foundation established by the 4D Construction Learning Environment project means it effectively demonstrates how industry-specific knowledge, simulation of the workplace and live projects can be integrated into the curriculum, enacting a change in the approach to learning in the various participating institutions.

Broad opportunist
The project was presented to the Heads of Australasian Architecture Schools at the AASA Conference in 2015. The adoption and translatability of the project to other architecture schools/programs would have been discussed. The project has the imperative to answer universities’ current requirement to increase workplace-integrated learning and industry-led research.

There are also opportunities to involve other disciplines, including computer science/human interaction technology and games designers, to fully exploit the conceptual foundations, development and outputs from this project towards the design of more immersive learning environments.

Broad systemic
The following are statements from my roles as immediate past chair of the National Education Committee of the Australian Institute of Architects (2010–2015) and presiding President of the Australian Deans of the Built Environment and Design (ADBED). (I hereby declare the potential conflicts of interest in the statements I make below, which are based on my knowledge and experience in leadership roles of the peak bodies of architectural and construction disciplines/profession, and is not a national endorsement of the project on behalf of the peak bodies.)

The 4D Construction Learning Environment project is timely because the architectural and construction professions are moving towards a greater degree of interdisciplinarity and cross-disciplinary collaboration, brought about by the rapidly changing technological landscape, the nature of construction, and new design and building procurement methods, processes and sequences.

There is also an unprecedented level of ongoing change to higher education in Australia, with the uncertain but imminent Tertiary Education Quality Standards Association (TEQSA) processes and the use of what was designed as the threshold learning outcomes (TLOs) for Architecture, and evaluations of the quality of higher education institutions for Building. The TLOs have very specific performance criteria that map directly onto the positive aspects of the 4D Construction Learning Environment project – namely, and in general: industry relevance, teamwork, critical
theory–practice relationships, and new technologies. Workplace-integrated learning is one of the key agendas of Universities Australia, which Australian Deans of Built Environment and Design (ADBED) is tasked to develop in the built environment and design disciplines.

The National Competency Standard for Architecture has been recently reviewed, and its implementation in the accreditation of architecture programs is currently undergoing a major overhaul. The project involves National Education Committee (NEC), ADBED and AASA, led by the Accreditation Council for Architects (AACA). The 4D Construction Learning Environment project has the scope to influence national policy in relation to new ways in which the relations between theory and practice, professional studies, contract documentation, building procurement, teamwork and ethical practice can be demonstrated. There is also a specific need for conceptualising analogue/digital relations for the online teaching of design and construction courses. The project team leader is currently a member of the Review Panel of the Australia and New Zealand Accreditation Procedure for Architecture Programs (ANZ APAP).
Appendix C
Student evaluation questionnaire
4-Dimensional construction learning environment questionnaire

Project Title: Developing a 4-dimensional multi-disciplinary learning environment for construction industry professionals

Principal Investigator: Dr Chris Landorf, Senior Lecturer, The University of Queensland

Co-Investigators: Associate Professor Graham Brewer, The University of Newcastle, Ms Kim Maund, The University of Newcastle, Mr Stephen Ward, University of South Australia, Professor David Williams, The University of Queensland, Dr Trish Andrews, The University of Queensland

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Introduction

This survey seeks anonymous feedback from students who have used the Advanced Engineering Building 4D construction learning environment in Semester 2 2015 in ARCH3220 Architectural Technology 5 available at: http://4dconstruction.uqcloud.net/VirtualTour/3D

The survey should take 5-10 minutes to complete. Results will be used to develop the learning environment for future use. Chris Landorf

1) Appearance – Did you like the appearance of the learning environment?

2) Navigation – Did you find the learning environment easy to use?

Please turn over
3) **Content** – Did you find the learning environment assisted your understanding of architectural technology (e.g. structure, environment and construction), if so why?

- **Strongly Disagree**
- **Disagree**
- **Neutral**
- **Agree**
- **Strongly agree**

4) **Learning** – Did you find the environment enhanced the architectural technology learning experience (e.g. observation, reflection and collaboration), if so why?

- **Strongly Disagree**
- **Disagree**
- **Neutral**
- **Agree**
- **Strongly agree**

5) **Improvement** – Can you suggest ways to improve the learning environment for future users?

Thank you