BIM-based Multidisciplinary Building Design Practice-A Case Study

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Abstract

Purpose / Context - As the emerging digital technology, Building Information Modelling has been applied in the multidisciplinary design work for sustainable houses. This study aims to input the real-world design context into the BIM pedagogy and to demonstrate the capacity of BIM in enhancing teamwork in the cross-disciplinary collaboration.

Methodology / Approach – A case study of a Saint Lucia-based residential house project was adopted by utilizing BIM as the platform to carry on the redesign plan differing from an existing design. Nine different student design teams from the University of Nottingham Ningbo China, each team consisting of students from architecture, civil engineering, and architectural environmental engineering, worked in the BIM-based platform to provide solutions on architectural model, structural design, cost estimate, and sustainability in terms of energy efficiency. Each team's design plan was presented and evaluated by academics, the client, and construction professionals.

Results – The case study demonstrates the capacity of BIM in assisting the cross-disciplinary project design. BIM learners gained the practical experience in the team design work. As the project deliverable, different design plans were evaluated by the client and the contractor for further developments. The BIM project experience from team members was also presented in this study.

Key Findings / Implications – The BIM education provides the insights of how colleague education could equip students with the state-of-the-art learning experience by incorporating the real-world project into the BIM pedagogy. BIM, as the coordination platform, could be fully utilized to implement the building design. This case project serves as an example of briding the gap between BIM academia and industry. Future BIM education could continue adopting the case study-based experiential learning approach and expand BIM applications from design to the construction stage.

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Originality – This work provides the case study in the pedagogical practice demonstrating the BIM-enabled multidisciplinary collaboration in architectural visualization, structural design, budget control, and sustainability strategies.

Keywords - Building Information Modelling, multidisciplinary collaboration, sustainability, cost estimate, pedagogy

1. Introduction

Building information modelling (BIM) could serve as the digital platform to enable multidisciplinary collaboration in the building project from architectural design, structural visualization, construction estimate, to building energy simulation. The following sections focus on the college BIM education leading to practical work, BIM-based multidisciplinary work, and BIM application in sustainability.

1.1. BIM education

Although BIM is expected to achieve multiple benefits in the project delivery including accurate geometrical representation of building elements, improved design quality, and better budget control as claimed by CRA Construction Innovation (2007), various barriers in achieving these benefits exist in BIM practice, one of them being the reluctance of experienced engineers or designers to switch to BIM from the traditional Computer Aided Design (CAD) as identified by Gong (2013). BIM education is important in the sense to work as pre-career training for college graduates in the fields of architecture, engineering, and construction (AEC) and to further reduce the industry investment in BIM training (Tang et al., 2015). College graduates newly entering the job market, although tending to be quicker to pick up the digital skillsets, their BIM work may need more inputs and feedback in terms of design feasibility and constructability from more experienced peers. Hence BIM education could embrace more real-world design and engineering practice rather than barely deliver the BIM software training.

It is believed that BIM education is not simply changing the engineering education tool from 2D CAD to 3D visualization (Tang et al. 2015). Instead, the collaboration was deemed the key of BIM implementation by multiple researchers from the perspectives of both academia and industry (Eadie et al., 2013; Szeda, 2013; Tang et al., 2015). BIM should not be merely adopted as the tool to generate drawings but a comprehensive approach for information management and teamwork (Sacks & Pikas, 2013). Personal BIM skills would significantly impact college graduates' career (Russell et al., 2014), and the BIM-enabled collaborative learning environment would prepare and equip students with collaborative problem-solving skills as stated by Mathews (2013).

1.2. BIM in multidisciplinary teamwork

BIM maturity levels are defined by the BIM Working Party Strategy Paper (2011) from 2D CAD-based Level 0, 3D-enabled data environment without integrations in Level 1, managed 3D environment with certain integrations in Level 2, to fully integrated data integration by "web services" achieved in Level 3. The BIM Strategy Paper (2011) from the UK government required the industry to achieve Level 2 by 2016. It is indicated that as the AEC practice moves towards higher maturity level, the interdisciplinary collaboration would become a more urgent need.

Singh et al. (2011) provided the framework focusing on the technical requirements for BIM to serve as a collaborative platform. A case study of landmark building using BIM-server was presented by Singh et al. (2011) to develop categories for the technical requirements, one of them being the design visualization and team communication. Complicated functional and technical requirements in complex building projects such as in the healthcare sector ask BIM to support the collaboration among different disciplines in an integrated approach (Sebastian, 2011). The BIM-partnering framework and development of the collaborative BIM model for the construction process were introduced by Porwal and Hewage (2013) in the public sector projects. BIM adoption would require certain changes in the existing practice to overcome the challenges within technical (e.g., data compatibility), procedural, and organizational (e.g., legal responsibilities) aspects (Porwal and Hewage, 2013). A BIM pilot project within the small-scale house sector recruiting project participants from multiple disciplines was presented by Sebastian et al. (2009) to demonstrate BIM's application in the integrated design and engineering. Multiple cases within different sectors of building projects in these studies have shown that BIM, as the digital platform, could enhance the collaboration within the project design and construction among different disciplines and parties.

1.3. BIM in sustainability

The demand for sustainable building facilities with minimal environmental impact is increasing (Azhar, et al., 2011). The early design and preconstruction of a building are the most critical phases for decision making in sustainability (Azhar, 2010). Traditional computer-aided design (CAD) lacks the capacity to perform sustainability analyses in these critical phases (Azhar, et al., 2011). Kriegel and Nies (2008) indicated that BIM could aid in sustainable design in the areas including building orientation, building form and envelope, daylighting analysis, water harvesting, energy modelling, sustainable materials, and site and logistics management.

BIM and sustainability, the two emerging subjects in the AEC fields, are in the need of bridging the gap between industry and academia (Becerik-Gerber et al., 2011). Since September 2014, The University of Nottingham Ningbo China (UNNC) has been keep developing the multidisciplinary-featured BIM education by linking BIM into sustainability and bringing the real-world AEC practice into graduates' BIM learning. The student BIM practice has also been raised from Level 1 to Level 2 to enable certain integration of project data. This study targets on the BIM-based cross-disciplinary team design adopting Autodesk Revit as the basic BIM tool with other visualization and energy simulation tools to provide the architectural plan, structural visualization, take-off cost estimate, and sustainable solutions for the Chateaux Georgia-Marigot Bay residential project located in Saint Lucia.

2. Methodology

This study focuses on the experiential learning approach to provide college graduates with BIM-based teamwork design practice. UNNC, as the first international university founded in China, launched the first BIM education module in autumn 2014. Aiming to raise the BIM education level from Level 1 to Level 2 in autumn 2015, the Chateaux Georgia-Marigot Bay residential building project was adopted as the case study. The optional BIM module was open to three major disciplines in the Faculty of Science and Engineering at UNNC. It recruited totally 54 final year undergraduate students evenly distributed from architecture, civil engineering (CE), and architectural environmental engineering (AEE) in the beginning of September 2015. These students have completed the core modules in their own fields of study but lacked the BIM operation skills or BIM-based design experience. Therefore, the BIM module is targeted at applying students' own fields of knowledge into the case project by utilizing BIM as the collaboration platform. The students were divided into six design teams and each team consisted of members from the three major disciplines to enable the cross-disciplinary collaboration. A four-week training of Autodesk Revit in three templates (i.e., Architecture, Structure, and Mechanical) was provided to all BIM learners in early September to early October during 2015 to according them with the operation skills of Revit. Although only Autodesk Revit was instructed through the BIM module, students were encouraged to use all potential software tools to assist the team design. For example, Lumion for the architectural visualization, Navisworks in 4D scheduling, and PV Designer for the photovoltaic system design.

Figure 1 displays the key dates of the project design process from September 2015 to January 2016.

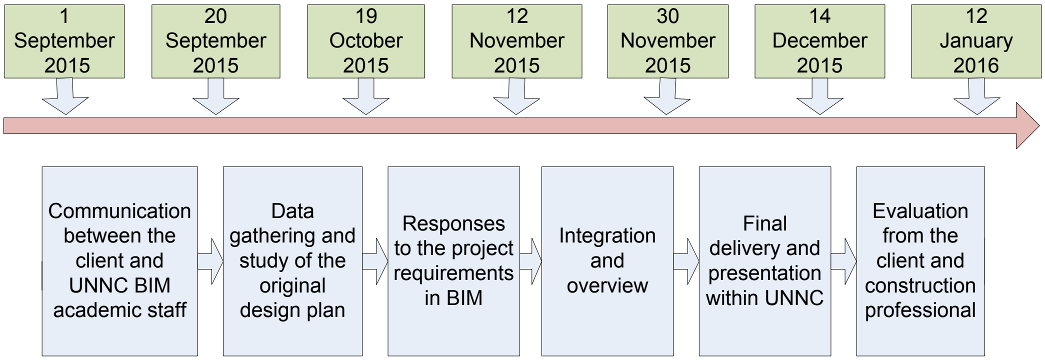


Figure 1 Work flow of the Chateaux Georgia-Marigot Bay residential project in the BIM pedagogical practice

Since the beginning of September 2015, the owner of the purchased land in Saint Lucia started communicating with UNNC BIM academic staff on the plan of the holiday style residential building. At that moment the site had been levelled and the topographic maps had been obtained. Apart from the project site information, there was also an existing design plan provided from a local Saint Lucia architecture and engineering design firm in 2D CAD drawings. The land owner was seeking an alternative plan with improved architectural aesthetics, possibly lower budget, and better energy efficiency in terms of electricity consumption. During the following three weeks in September 2015, the land owner specified the project requirements in these multiple areas. A project brief was composed according to the communication results and released to the nine student BIM teams on 20 September 2015 asking for the data gathering and study of the existing design plan by 19 October 2015. Specifically, each team was requested to perform the following tasks:

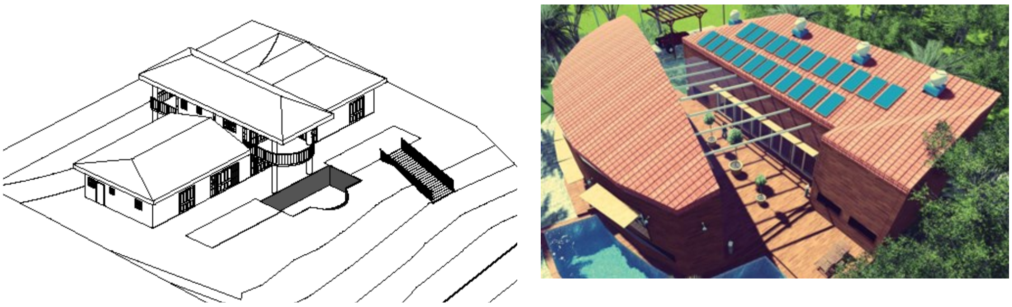
1) The existing design plan to be reviewed and summarized
2) Alternative architectural forms (e.g., round house or tea house) to be reviewed
3) Alternative construction techniques to be explored, with an emphasis on prefabricated buildings such as kit house and encapsulation insulation frames
4) The micro-climate of San Lucia (e.g., wind and solar directions) to be investigated
5) The references on termite proof timber materials to be reviewed and their engineering properties to be investigated.
6) Structural design guidelines on hurricane resistance to be reviewed
7) A redesign proposal to be completed meeting the client's requirements in architectural, structural, and building services perspectives

3. Results and Discussion

Totally nine redesign proposals were received by the deadline and assessed by the UNNC BIM academic staff strictly following the seven pre-determined evaluation criteria. For example, most of the design teams had suggested a certain type of timber materials to be used considering its local availability, unit price, and engineering properties (density, strength, termite resistance, etc.). Schematic architectural models were proposed at this stage. The feedback of the proposals were returned to each team within one week and teams were guided to continue with the design. The team design work was performed in the follow-up stages between later October and early December in 2015. The team presentation of the BIM-based final project design was delivered on 14 December 2015 and evaluated by three UNNC academic staffs. Each member of the team presented the individual contribution to the project. The design development in this discussion is divided into these subsections including the architectural plan, structural analysis, cost estimate, energy simulation, and the integration experience.

3.1. Architectural plan

Each design team started the project by converting the original architectural plan from 2D CAD into 3D visualized architectural models within the topographic context as displayed in Figure 2-a). The teams also evaluated the existing design plan before proposing the redesign model. For example, one group stated that "the existing architecture has relatively complex circulation which is not easy for people to get access to each individual rooms in a short time", and another group commented that "the existing plan sounds easy to build but lack of sufficient connections among various spaces." The redesign model was proposed by each team following the existing model. Figure 2-b) displayed one selected architectural model from the design teams as an example.



a) The visualized original design b) The redesign model from one group

Figure 2 The existing architectural plan and a selected redesign proposal

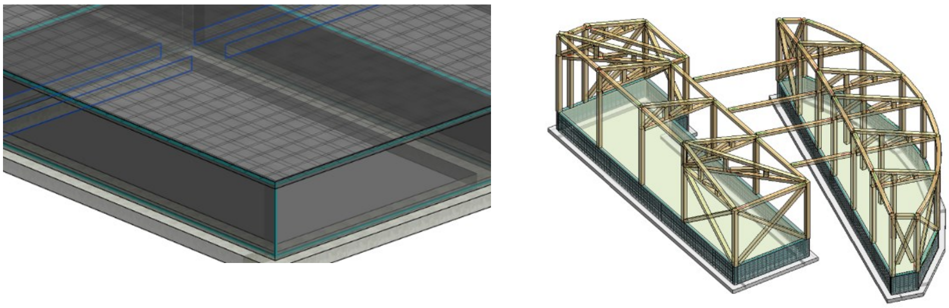
The rational of the architectural redesign in Figure 2-b) was presented by the team that

"The project focused on simplicity and the compactness of a kit house, yet it strives to achieve an aesthetic quality informed by the previous analysis and design experience. The tropical climate in Saint Lucia have particularly strong winds from the east and mildly hot climate all around the year. The new redesign programme offers cross ventilation as our main cooling system. The design compacts the living area and separates it from the rest area to enhance the space integration."

In light of the BIM input in the architectural design, the architecture students claimed that the Autodesk Revit-based BIM platform was not as effective as other tools such as Sketchup or Rhinoceros in communicating ideas in the conceptual design stage. This was consistent with the findings from Thomsen (2010) that the BIM technical platform limits the choices of possible solutions, provides extra requirements than traditional projects and changes the roles in the design stage. However, the design team also stated that "BIM technical platform turned out more useful in delivering the design model into drawings, rendering and videos in the later design stages."

3.2. Civil Engineering work

The Revit Structure template was adopted to present the structural design. Figure 3 displays the structure model continued from the redesign model in Figure 2-b).



a) Reinforced concrete foundation wall b) Timber framing structure

Figure 3 Structural visualization of the project

The data of materials properties were stored in Revit by creating new families. For example, the compressive strength of the Greenheart wood at 91.7 MPa.

BIM was used to generate the take-off material spreadsheet to assist the cost estimate. The estimator from each team compared the redesign plan and the original design following certain estimate codes (e.g., Spon's Architectures' and Builders' Price Book, 2015). The price from the same group redesign presented in Figure 2 was provided at € 252, 457.1, compared to the budget following the original plan at € 233,561.5. The higher budget following the redesign in this group mainly resulted from the sustainability strategies as described in the next section.

Detailed cost break-downs based on the quantities generated from BIM were included in each team's work. Table 1 lists one example of the taka-off estimate within the plumbing system.

Table 1: Take-off estimate of the plumbing section

Mechanical Equipment Schedule		
Family	**System Name**	**Cost (€)**
Storage Tank - Horizontal	Domestic Cold Water 1,Domestic Cold Water 8	187.05
Water Heater - Tankless	Domestic Cold Water 1,Domestic Hot Water 1	426.99
Inline Pump - Vertical	Domestic Cold Water 1	161.25
Inline Pump - Vertical	Domestic Cold Water 1	161.25
Water Filter - Wall Mounted	Domestic Cold Water 6	139.97
Storage Tank - Horizontal	Sanitary 1,Sanitary 9,Sanitary 6	264.19
Water Filter - Wall Mounted	Sanitary 1	139.97
Inline Pump - Vertical	Sanitary 1	161.25
Water Heater - Tankless	Domestic Cold Water 1,Domestic Hot Water 3	426.99
Storage Tank - Horizontally	Hydronic Supply 1,Domestic Cold Water 1	264.19
Roof Drain	Hydronic Supply 1	109.65
Roof Drain	Hydronic Supply 1	109.65
Total		2,552.4

3.3. Sustainability

Sustainability was one of the project goals pursed by design teams. Each team was encouraged to explore multiple sustainability strategies but with the reasonable budget. Using the same teamwork presented in Figure 2-b) as an example, the BIM team targeted on utilizing natural ventilation, thermal performance enhancement, greywater recycling, and renewable energy application. Figures 4 and 5 illustrate some of these strategies in this team project.

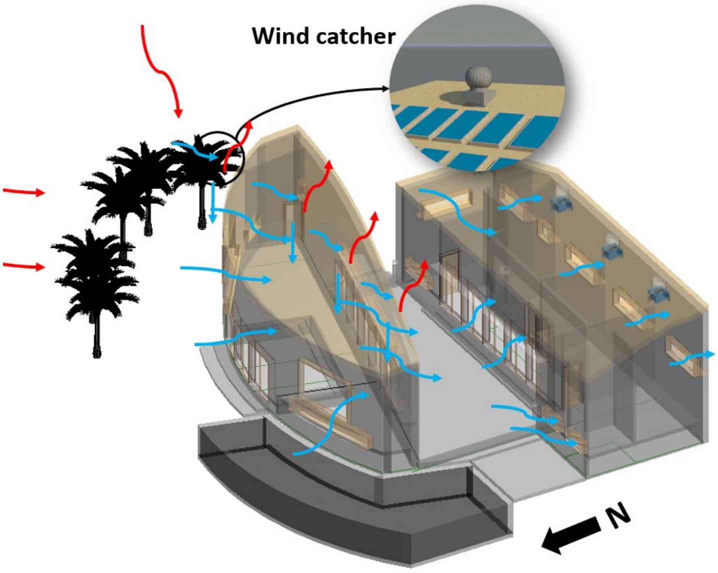
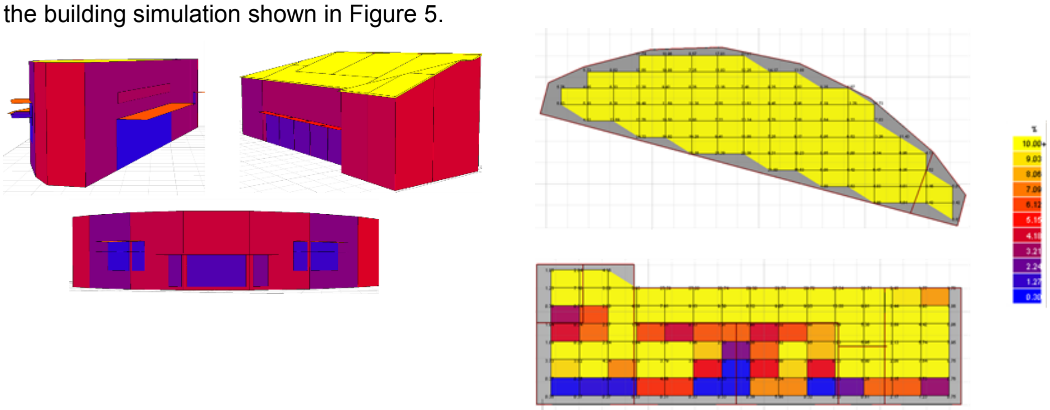


Figure 4 Utilization of natural ventilation

Based on the temperature and thermal comfort model, the natural ventilation was proposed as one passive strategy. The wind direction illustrated in Figure 4 came from the micro-climate study in Saint Lucia to enable the cross ventilation. Other passive strategies were also suggested and included in Revit families, such as the building fabrics in increasing the exterior wall's thermal resistance. The shading devices were designed and integrated in both the visualized model and the building simulation shown in Figure 5.



a) Simulation of shading device

b) Simulation results of lighting condition

Figure 5 Building simulation

Adopting these passive strategies, the energy simulation results indicated that the monthly energy consumption within the redesigned building could achieve as much as 53% of reduction per m^2 compared to the original design. More sustainable approaches were also incorporated in this team design including solar panels to power the air conditioning and the grey water recycling system. The grey water system was integrated in the building plumbing system together with the rainwater collection system, the sewer system, and the cold and hot water systems. According to annual energy consumption of the redesigned building at 5,923 *kWh* from the simulation results, the installed solar panels could contribute to 30% of the total energy from the generated electricity. Various other passive and active strategies were proposed by eight other design teams, supported by individual team's energy simulation results in achieving energy efficiency. These strategies included but were not limited to wind turbines, different types of solar panels, and adjusted window-to-wall ratios, etc.

3.4. Discussion of BIM experience

Students from different disciplines shared their collaboration experience from this BIM teamwork. The main benefits and disadvantages of adopting BIM in the team project are listed in Table 2.

Table 2: Summary of experience learned from BIM practice

Benefits from BIM adoption	Disadvantages and challenges in BIM usage
• Improved communication from the virtual environment provided by 3D visualization • Enabled building information exchange • Enhanced collaboration among different disciplines • Efficiency in converting building models into drawings and rendering	• Lack of interoperability when exchanging building information among disciplines • Lack of sufficient families in the existing library of Revit • Lack of standards for BIM implementation • Difficulty in expressing architectural ideas in the early design stage • Lack of user-friendliness in MEP design

One example for the enhanced collaboration among different disciplines listed in Table 2 is that the visualization and design of roof overhang was not only performed by the architect considering aesthetics but also with the input from building services engineering in lowering cooling load. Besides the shared experience listed in Table 2, one BIM group commented BIM's impact on leadership that "BIM changes the role allocation in the project. Whilst architects normally take the lead in the project adopting conventional process involving manual and CAD system, in the BIM-implemented project, the leader is supposed to be the one most familiar with BIM and capable of using BIM technologies regardless the professions, which means either architects, civil engineers or architectural environment engineers can take charge of the project as the project manager." This shared experience from BIM learners is highly consistent with the industry findings from Thomsen (2010) that the BIM technical platform changes the role in the design phase and creates the risk to the role of the architect being replaced by a more computer skilled designer or engineer. The similar experience from both the academic pedagogy and industry profession indicates that through proper set-up of pedagogical activities, college graduates could gain the real-world experience which would prepare themselves in their future AEC career. When Becerik-Gerber et al. (2011) stressed the importance of understanding from both industry and academia to bridging the gap between the two worlds, as both sides might face the same challenges when adopting BIM, this case study provides some hints on some of Becerik-Gerber et al. (2011)'s research questions such as whether the BIM education in universities would increase the speed of adoption in the industry. It also serves as the solid example for integration of disciplines in the AEC education as emphasized by Becerik-Gerber et al. (2011).

The pedagogical practice in this BIM case study demonstrates how BIM platform enhanced the multidisciplinary work in the pre-construction stages including architectural design, structural analysis, cost estimate, and sustainability strategies. It is worth noticing that this case study created the BIM platform with available software resources within UNNC that enabled teamwork design. Team members received the same BIM training, stayed in the similar knowledge level on BIM and their own fields of experience, and had the passion on adopting BIM in the design practice. All these factors enabled the effective communication among different disciplines in the project design. Team members from various disciplines all had early contribution in the design stage, and shared the same goal of delivering the team design plan with BIM as the collaboration vehicle. However, when moving from the pedagogy to the real-world case, more complicated factors would be counted towards the BIM implementation. For example, data compatibility issue caused by different BIM tools used among disciplines, the BIM experience level among different project teams, the client's attitudes towards BIM, and work plan on carrying the BIM platform during the project delivery process, etc. Therefore, there would be more barriers to overcome in the industrial work to fully launch the BIM technical platform. Nevertheless, gained practical experience in BIM teamwork of the college graduates, the future AEC industry professionals, could bridge the gap between the AEC education and the job market.

4. Conclusion

This case study links the real-world design project into the BIM pedagogy with an emphasis on multidisciplinary collaboration, which motivated college AEC graduates to apply what they have learned from their own fields of expertise into practice within the BIM platform. College graduates from multiple disciplines gained the integration experience in BIM Level 2. BIM, as the communication platform, has demonstrated its potential in integrating different disciplines in multiple design stages from conceptual design, schematic design, to design development. Future BIM pedagogy could expand the BIM practice further to 4D scheduling and visualization on construction jobsites following the design stage.

AEC graduates were trained with the teamwork and problem-solving skills throughout this case study. For example, the architecture and structural engineering students happened to argue on maintaining the architectural aesthetics and the structural simplicity using the 3D visualized model until they reached the agreement. The BIM-based teamwork experience shared from the design teams was somewhat similar to the industry perceptions including how BIM affected the traditional role of architects. This conveys the information that it is feasible to adopt the experiential learning approach for BIM learners to gain the practice in the real-world context.

This case project built the connections among BIM academia, the client, and AEC professional. As the project deliverable, the nine redesign plans were sent to the land owner and the owner's procured contractor in early January 2016 for professional assessment. These nine redesign proposals were ranked and commented with relevant feedback provided on further improvements of the current design. Future BIM pedagogy could continue the case study approach with the client providing the site information and project requiremenets, the college BIM team working on the design plan in an integrated approach, and the final design development being assessed by the client and AEC industry professionals.

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