Multi-disciplinary learning from OpenBIM

Tim McGinley, timmc@byg.dtu.dk
DTU Byg, DTU, Lyngby, Denmark

Thomas Krijnen, t.f.krijnen@tudelft.nl
TU Delft, Delft, The Netherlands

Abstract
Traditional building information modelling (BIM) education emphasises the tools and the modelling rather than the analysis of the model. Rather than simply provide training for proprietary software, university BIM education could support innovation through the development of standardized OpenBIM tools, data and processes, supporting students to analyse their own models and learn *from* BIM rather than simply learn *howto* BIM. This paper presents a family of courses, wherein; (1) postgraduate students in the autumn, develop OpenBIM tools and processes, that are used in the spring to provide rule checking on (2) the BIM modelling for an undergraduate course and (3) the design models of a post graduate multidisciplinary course. Feedback from the tools is integrated into the students' personalized course homepages. An open web-based platform is proposed where students in the design and modelling courses receive feedback on their BIM from tools developed in the BIM tool and analysis course.

Keywords: OpenBIM, Education, Learning Management Systems, IFC

1 Introduction

From a teacher perspective, BIM education can focus on the questions of finding the right balance between (1) theory and practice; (2) technology and process; and (3) traditional and emerging (construction process) methods (Puolitaival and Forsythe, 2016). However, it is important to focus on what the student learns rather than what the teacher teaches (Berglund and Lister, 2010). The challenge of BIM education is therefore to know what the students need to learn. To address this, we need to look at how students will use BIM in their future careers and ask if what we are teaching is aligned to the skills and abilities they will need in their future. For instance, in a professional project, building information models (BIM) are analysed by the professional to *guide a project stakeholder on the state of the project*. However, in an academic project, student BIM models are typically analysed by the teacher *to assess the quality of the students modelling skills*.

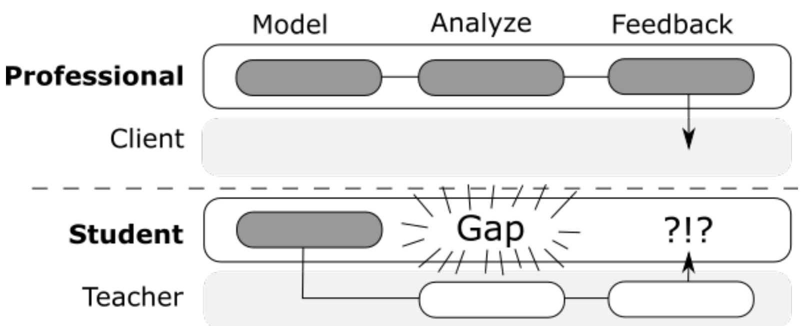


Figure 1. The analysis gap in traditional BIM education

Both contexts require the user to create BIM and this is what is covered in the traditional 'teaching students to use BIM tools' type of BIM education. However, a limitation of traditional BIM education is that the analysis stage is typically performed by the teacher and the result is reported to the student. Conversely, in the professional role, the analysis is performed by the professional and then reported to the client or appointing party. The authors foresee that the analysis tasks will gain importance with developments in big data, digital twins and sustainability requirements for instance. This means that the student is missing out on the ability to *learn from BIM* and share this learning with others, and the teacher is 'wasting' time doing the student's work, which could be invested in the development of the course. This paper therefore aims to identify an approach to support students to learn from the BIM they produce by encouraging them to analyse their BIM models and communicate this guidance to another stakeholder in the project.

The higher education of building industry professionals requires an introduction to the academic knowledge and the profession they are entering. It is important to provide a model of BIM education that is flexible and appropriate to adapt to the evolving needs of the professional context. How students are educated for their future professions has been described as the 'signature pedagogy' of the profession. Shulman (2005) defines three factors for the pedagogy which are weighted differently depending on the profession; to think, to perform and to act with integrity. These factors are remarkable for two reasons. Firstly, because they are normally weighted similarly across the same courses in different universities. Secondly, they not only act to preserve professional practices, but changes in signature pedagogies have the potential to change industries (Shulman, 2005). In relation to the challenge of supporting students to learn *from* BIM we could (1) consider the changes required to BIM education for students to learn *from* BIM and (2) to identify a vision of the future of our profession and (3) consider how we can alter our pedagogies to support this. Figure 1, shows that the typical learning experience and the professional experience are not aligned in terms of BIM, raising the question, 'what is the best learning experience for students to learn *from* BIM?'

2 Learning from BIM

Traditional BIM education can be limited to: what tools to teach and if it is better to analyse existing models or model from existing drawings. In a single BIM course, it can be difficult to explore all these questions. This paper proposes a BIM Education framework that decomposes the signature pedagogy of BIM education over a family of parallel courses to provide: (1) the students with live design experience; (2) a focus on standardization of processes; (3) a living lab for the development of new analysis tools; (4) a focus on Industry Foundation Classes (IFC), the most prevalent open standard in BIM that, by its open nature, allows a deep understanding of BIM (5) automated feedback to the students on their progress through their learning management systems. So how can we share different learning experiences across multiple courses? Tinto (2017) provides a model of student motivation to support universities to view education from the perspective of the student and what they are to learn. Applying this to BIM education, Succar et al (2013) present a framework for what the students should learn in BIM. Succar's framework includes the competencies of knowledge, skills, and personal traits. Furthermore, Succar defines three competency manifestations: as an ability (inert or learned); an activity (a set of tasks); or an outcome or measurable deliverable. In BIM education the skills and abilities can be invisible in the assessment which can focus only on the output. In the fixed BIM example, the skills and even the tasks achieved by the student are not explicit and currently need to be inferred by the teacher by analysing their output. The ability, activities and outputs assessment implications for the three principles to support students to learn *from* BIM are described below.

2.1 Principle 1: Provide a live design experience

From a pedagogical perspective, it is easier for the student to model a 'fixed' solution and to not have to 'worry about changes' in the model. An example is to provide students with an existing professional 'full BIM' model. However, the level of detail in such a model means that 'they typically do not know how to unravel or interrogate the model quickly enough to achieve the intended learning or to prevent stalled learning situations' (Puolitaival and Forsythe, 2016).

Furthermore, concern of IP and other legal issues can make it difficult to source such models. An alternative (fixed model approach) is to provide them the drawings of a predesigned building and ask them to model it in a BIM tool (and then analyse it). The relevance of fixed project could be improved by providing students with the original requirements (brief) for the building so that they can assess its performance. Therefore, there are limitations to the use of fixed projects in BIM education. The alternative to fixed projects as suggested by Puolitaival and Forsythe (2016) is to simulate a real-world project which follows a real design process. Live projects, that are dynamic and change frequently, are the norm in professional practice. However, these 'live' projects, bring their own complexities, which can also reduce the student's potential to learn from BIM. These include the challenges of working with others, working with inconsistent data (and trying to make it consistent), reconciling different disciplinary needs on the project. So, we need a model of education that supports students to learn *from* BIM in a live design experience.

2.2 Principle 2: Provide a focus on standardization of processes

BuildingSMART offers certification for BIM courses to demonstrate that they cover the principles, tools and standards of OpenBIM. They emphasize that they are not interested in delivering training programs but want to: standardize OpenBIM training content; support and approve training organisations and test and certify individuals who have undertaken approved training courses (BuildingSMART, 2021). A common European BIM curriculum could build on the buildingSMART certification process to create a common menu of elements for learning from BIM. This could be focused on use cases as a representation of a standard set of problems for BIM, a starting point to this could be Penn State's "Uses of BIM" (Messner et. al., 2021) and managed in the use case management (UCM) processes proposed by BuildingSMART. Furthermore, the international standard ISO 19650, provides a common framework developed from BS / PAS 1192 to standardize the processes in the AEC industry. From an OpenBIM education perspective ISO 19650 offers a framework for the students to contextualise the BIM use cases they are focused on. Hansen (2021) explored the potential of modelling this in the Business Process Management Notation (BPMN) format. The BPMN format enables the representation of processes as tasks in stakeholder specific swimlanes. BPMN is a common format to model business processes and its integration into the AEC provides access to standards and tools from parallel industrial disciplines. It is also the format specified in the Information Delivery Manual (IDM) standards (ISO 29481-1:2010). Focusing on ISO 19650 rather than specific BIM tools in education provides an opportunity to model processes in a software agnostic approach and consider not only the information to be exchanged (as per IDM), but the *service* that needs to be procured, performed and delivered. This provides an opportunity to show the students - *why* we are doing BIM, i.e. to offer a *useful service* to another stakeholder in the project. Furthermore, it provides an opportunity for the student to imagine and build their own internal process model for real projects scaffolded by international standards that they can then apply in their future industrial practice. Ultimately these tasks could be collated as part of an OpenBIM ecosystem of tools, processes and data, with the ISO 19650 framework providing a backbone to explore options for automation and service thinking in the future (Hansen, 2021). However, this OpenBIM ecosystem presents new challenges for teaching and learning as multiple frameworks and languages could be explored.

2.3 Principle 3: Provide a living lab for the development of new analysis tools

A recent study in the UK indicated that there is an ongoing convergence in recent years towards Autodesk's Revit software (Day, 2020). There is therefore a risk that if the main question of the course is 'what BIM tools should we teach?' that we may all eventually converge on the same answer. Satisfying the *perceived* immediate needs of the industry and our students we are preparing for that industry, leads BIM education to focus on training in proprietary software tools (Sampaio, 2021). It is therefore important to ask not just *what* are we training our students for, but *when* are we training our students for? If we are training them for the future, the paradox is that their training will affect that future. Do we want to support a monopoly on tools or do we want to actively contribute to an innovation ecosystem of tools (Gu et. al. 2015; McGinley et. al.

2021). In this sense modelling student abilities for BIM requires that we first define a vision of that future context and align our signature pedagogies in BIM education to that vision. The alternative is that the current signature pedagogies, which focus on the immediate needs of industry, provide the inertia to undermine the futures they are potentially capable of. If universities had the same license fees that are experienced in professional practice, perhaps they would also be questioning the value that these tools add to our industries as is happening in relation to the fees the profession pays to use the tools (Day, 2020). The status quo of focusing our BIM pedagogies on the learning of specific proprietary software, transfers the industrial (societal) cost of BIM education to the companies that are then required to pay the software licenses for the career of that professional. Viewed in this way from the lifecycle cost (to society) of BIM education, University BIM education could reposition itself as a powerful stakeholder that can affect the future direction of the industry through BIM education. Universities with BIM courses should be cognizant of the innovation and societal value that our subsidized training in proprietary BIM technologies provides for the major software companies. Therefore, part of our role should be to enable the students to assess what tools are appropriate for what BIM use cases. A healthy approach from an innovation perspective would be to encourage a wider selection of BIM tools. This may reduce the student's time to analyse the models they produce. However it will also increase the relevance of interoperable data exchanges and standardized modelling of processes in their education.

2.4 Principle 4: Provide a focus on Industry Foundation Classes (IFC)

The Industry Foundation Classes (IFC) are a prevalent open standard to exchange building models. A variety of tools exist to programmatically analyse such models. IfcOpenShell is a software library for working with IFC building models. It can read and write files and interpret the implicit procedural geometry definitions (such as Boolean operations and sweeps) into an explicit Boundary Representations (BRep). The core library is written in C++, but it offers Python bindings for an (arguably) more readable syntax and less need for specialist software such as compilers. High level utility libraries such as convenience methods to retrieve all properties (See Listing 1) of an element further reduce the threshold to enable engineering students to get started with IFC programming and analysis.

Listing 1. Example code to derive the gross floor area of a model by summing the area of individual spaces

```python
import ifcopenshell
import ifcopenshell.util.element

f = ifcopenshell.open("duplex_a.ifc")
def get_area(elem):
    psets = ifcopenshell.util.element.get_psets(elem)
    for name, values in psets.items():
        for prop, value in values.items():
            if prop == 'Area':
                return value

print("Total GFA:", sum(map(get_area, f.by_type("IfcSpace"))))
```

In the case, from the perspective of Succar's framework, the outcome is the IFC file, from which we can infer an ability of the student to construct the model and overcome the issue to achieve this. In the future it may be also possible to infer the activities involved in developing that outcome. Related to this, IFC contains the concept of IfcOwnerHistory, but it is not meaningfully used in today's authoring tools and could potentially only be used to associate a last-modified time to elements in the export, not a list of changes and deletions. As mentioned in the previous section, an ecosystem of tools has been developing in the open source community. Code sharing repositories such as Github support collaboration in these communities. Code review is a common practice in software engineering, where code assessed by a team member before it is merged into the main product, iteratively refining the solution. Also automated solutions are in place for code analysis and so-called linters can be used to automatically reformat code for legibility. Employing such approaches in BIM education would support students to strive for maintainable code in the development of their tools and knowledge sharing among team members. The python programming language is appealing due to its syntax and straightforward development approach, but, in addition to that, it also caters to an immensely broad set of available modules for, for example, data science, machine learning and web development. Web microframeworks such as Flask make it possible to create simple interactive websites that could be used to develop microservices for instance to analyse the tools. In that way the process of acquiring feedback can be turned into an experience that can be tracked. From an educational perspective the big change is that this toolchain (IfcOpenShell and Python) can make it possible for students to build the analysis tools themselves. This opens interesting questions about what analysis to perform and to refocus on what use cases and uses of BIM we are addressing. The challenge is therefore, that this approach relies completely on the *outcomes* manifestation of learning. The tasks and skills are not directly evidenced and need to be inferred. A useful extension for this approach would therefore be that the student identifies that a certain skill is required by the AEC industry for instance. To achieve this, Succar demonstrated that it is possible to develop a taxonomy of BIM skills. If it were possible for this taxonomy to have a semantic structure so that students could identify a tool they wanted to develop and then be integrated into a Learning Management Systems (LMS) that could provide feedback to a student in a particular use case, for instance energy analysis, this could provide richer feedback to the student.

2.5 Principle 5: Integrate realtime analysis and feedback through the LMS.

Various platforms offer parts of BIM or project management functionality, such as: code repositories, model viewing and checking, learning management systems, but in typical courses these remain silos without interaction. Beetz (2019), provides a good example of a tutorial to support students to learn the concepts of IfcOpenShell and Python using Github. Whilst these tools offer an opportunity to store and display assignments and possibly support submissions. They do not (off the shelf) support the assessment and tracking of the students learning. For this we need to consider Learning Management Systems (LMS). Popular examples include Moodle, blackboard and newer tools like BrightSpace. Like BIM tools, there are multiple vendors and attempts have been made to support interoperability and learning information between different systems. Some of this functionality is provided in extensibility of the systems by means of what is called an Application Programming Interface (API). The main interoperability effort between different Learning Management Systems is called xAPI (eXperience API) (Rustici, 2021) and can be seen as a standardized approach to encode and exchange learning experiences in an LMS and the tools that integrate with it. xAPI provides structural interoperability by means of grammar, syntax and mechanisms for information exchange. However, it does not contain an actual ontology or taxonomy of the potential experiences, outcomes and actions. Therefore, it lends itself as a good candidate for how the kind of taxonomy suggested by Succar could be implemented in an LMS. Therefore, the aim of this paper is to support the use of BIM as an educational tool and integrate it into a learning management system to offer a paradigm shift in BIM education from learning *howto* BIM to learning *from* BIM. Finally, it considers if the model presented could inform a new model of working in 'the real world' that is also based on learning *from* BIM.

3 Methodology and case studies

This paper applies the 5 principles above to a family of three loosely coupled courses described below. The experience of applying the principles in these courses is then discussed and implications for future work are identified.

CS1 **Undergraduate BIM Course:** Previously, students worked in small teams to produce architectural, façade and structural models of an existing building on campus from drawings and site visits. The output was submitted as a native Revit file which was assessed in a resource intensive manual process by the teacher against a spreadsheet of criteria to assess the quality of the models. This reduced the opportunity to provide feedback during the course, as the number of the students has increased in recent years. In the case study, a set of rules was defined in python to automate the assessment of the students' models in an undergraduate course and the potential for the students to work on a live project was explored.

CS2 **Postgraduate (Advanced) BIM Course:** Previously students worked on different subjects and practical assignments each week covering a range of BIM and Open BIM concepts. This provided a good overview but made it difficult to see the connections between the concept and how to apply them in practice. The course output consisted of 13 reports (one each week) written in LaTeX and uploaded separately to the learning Management System (LMS) as a PDF. This meant that it was not possible to provide timely feedback due to the high assessment load of the course (13 reports x 90 students). Therefore, a simpler more focused structure is required that enables the students to see the connections between the activities and reduce the assessable outputs, to increase the potential for feedback. In the case study for this course the students identified their own use cases and supporting data from a fixed IFC model to develop tools to address the use cases using python and IfcOpenShell.

CS3 **Advanced Building Design:** Provides an example of a simulated collaborative project to support BIM education as advocated by Puolitaival and Forsythe (2016). The course is a post graduate interdisciplinary design studio (Diedrichs et. al. (2011) and Karlshøj (2016)) and has been running for 12 years. The course aims to encourage students to develop Open BIM models to support their investigations, however despite several innovative approaches over the years, the models are typically developed too late in the process to be useful in early collaborative decision making. Furthermore, despite the intention to develop interdisciplinary solutions, the teaching for the course is conducted in disciplinary silos, which can make it challenging for the students to question disciplinary conventions and assumptions. In this case study an analysis approach based on elements, aspects or systems of the building rather than disciplines per se, is explored as an approach to support the students to identify interdisciplinary solutions.

4 Findings

This section describes the results of applying the principles to the 3 case studies and future directions based on each of the principles.

4.1 Principle 1: Provide live project design experience

The postgraduate design course (CS3) provides students with a 'realistic' simulation of the challenges of working on the multidisciplinary design of a complex (advanced) building. The course has had a strong focus on multidisciplinary collaboration and BIM modelling and analysis. However, the BIM modelling was typically performed too late in the course to be useful to the students and support their analysis and future design decisions. Furthermore, in an engineering school, analysis of real designs is key to the students developing the skills they need to offer guidance to the other disciplines in real projects. Therefore, courses that simulate multidisciplinary design processes are precious and should be used to provide a realistic context for analysis courses for instance. Therefore, rather than the students in CS1 modelling a fixed building they could instead support the modelling the live project in the live CS3 course. Some students appreciated this approach, but many found that the coordination it required, reduced their ability to learn *from* BIM. In future years the live project connection between CS1 and CS3 will be offered as an option to students that want to explore this.

4.2 Principle 2: Provide a focus on standardization of processes

A major shift for our students is to consider their future work as providing a service to another discipline, rather than performing a function within their own office. To make this clearer, students were encouraged to consider the service they are offering. In CS3 the idea was to use ISO 19650 as a basis. Normally the students were divided into teams and filled one of six disciplinary roles in those teams. This was organized around a (real) blackboard in a shared teaching space. Due to corona restrictions this was not possible. Alternatively, the students in CS3 gave their preference for which subject they wanted to represent. They were then divided into 6 subjects. The Project Management (PM) subject was then further divided into 10 building teams. These teams each defined their values in terms of cost, sustainability and time for the project. The remaining subjects were then invited to present to the PMs and both the subjects and the PM rated each other. These ratings were then use by the teaching team to define the teams. Following this, students in CS1 were invited to view the interim submission of the teams in CS3. The CS1 students ranked these and the teaching team assigned them to a team in the CS3 live project. The intention was that this would be automated through ISO 19650 processes, and this is what we intend for next year. This will involve greater integration with the tool development in CS2. Ideally CS2 would develop tools to assess the successful delivery of the promised service.

4.3 Principle 3: Provide a living lab for the development of new analysis tools

CS2 supported postgraduate students to write Open BIM tools and rules to address specific use cases. In this way it used a spiral pedagogical approach to allow the students to iteratively develop solutions to a self-defined use case until they have defined their own tool. This process was divided into 5 steps. (1) **Dashboard:** use the data in an excel version of the duplex IFC model to create a dashboard sheet including things such as gross floor area etc. This provides an early deep dive into IFC. (2) **Rules:** use Python and IfcOpenshell to get similar data to that which they got in the previous assignment. (3) **Use case:** focus on a specific BIM use case and propose a new process from this (modelled in BPMN). (4) **Data:** Create an excel doc with all the data that you need to run your analysis. This data should be extracted from the IFC model using IfcOpenShell and enable the students to (5) **Custom tool:** Finally develop a tool in Python using IfcOpenShell to extract data from the model (or read assumptions from an excel file as necessary) to perform a specific task in the use case identified in assignment 3. The tools were developed with the assumption that they would be run by a human operator and there was a wide range in the quality in the outputs. There should be a 6th stage wherein the tool is called and executed in the alternative workflow (use case) proposed in stage 3 in order to validate the proposed solution produced by the students. This would require some form of standardization in interface and output formats such as, for example, BCF (Bim Collaboration Format, a light-weight XML schema to exchange comments and issues pertaining to BIM models and its elements). This additional step could mean that students could progress through the course at their own pace, enabling them to back track and adjust their approach and or assumptions, if the solution is not successful the first time. Additionally, in future iterations, students will be encouraged to use different tools, in this semester, some took this opportunity including an example of a BIM interface in MatLab, as well as Revit and Dynamo. Also, the students should be introduced to the different licence models at the start of the course to support them to develop tools that support the innovation ecosystem if they wish to contribute to it.

4.4 Principle 4: Provide a focus on IFC

A custom rule checking system was developed by the authors to automatically check the models produced in CS1 against a list of rules contained in the original spreadsheet. The rules were written in python and executed in a .bat file (Figure 2).

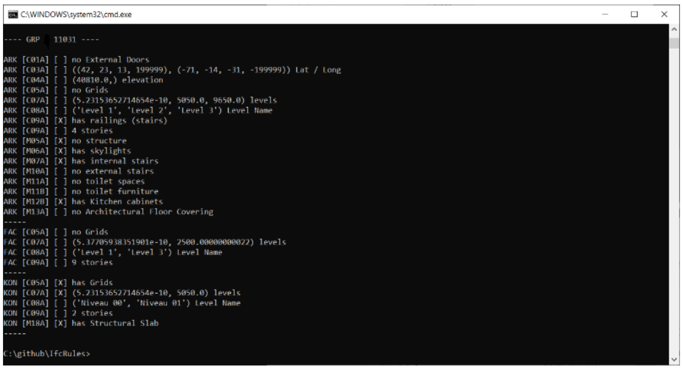


Figure 2 Example of the automated rule checking for the different disciplinary models submitted by the student groups. The rules are all given unique codes

The use of OpenBIM unlocks a large number of potential analysis tools as well as the possibility for programmatic analysis using open-source software modules. A fully explicit human readable serialization of the model for inspection by the student provoked a more in-depth understanding of how the model is constructed. However, whilst this made it possible to provide feedback earlier, it was not possible in the current course as it took longer than anticipated to encode the rules for the spreadsheet into the automated rules. Therefore, in future semesters it will be important that the rule checking is available to the students to check their own models and receive continuous feedback during the course. Ideally the rules could be developed by students in CS2, to relieve the effort on the teacher to develop the rules and provide an opportunity for the students to learn from *developing* BIM tools to specific use cases.

4.5 Integrate realtime analysis and feedback through the LMS.

Figure 3 describes a workflow that connects building design, writing and implementing model checks, reporting into a unified experience for students by developing a system that connects Brightspace (The LMS used in the case study courses), Github and a web-based viewer. Within this (eco)system, students with different backgrounds, seniority and from different courses, interact. The left of Figure 3 describes the interaction with the tool development and a cycle of pull requests to a global repository and review by the course instructor using Github in CS2. On the right a cycle of uploading the model to an online viewer where a set of model and design checks are run for CS1. The checks are populated by the code repository. The interactions are stored in the LMS. The system as envisaged here is not yet fully operational.

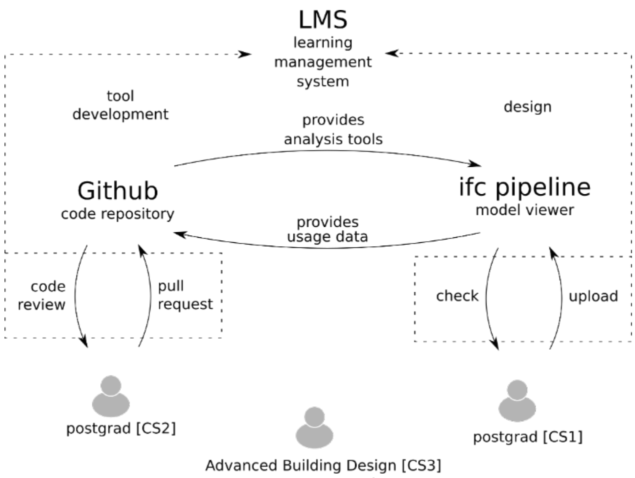


Figure 3. Schematic framework to support the learning from BIM course ecosystem

A focus on providing the structure for the student to learn and the feedback on their work can be supported by an integration of the BIM tools into the LMS. This is exciting, but complex as live testing in the LMS is difficult and navigating the LMS APIs is challenging. The students responded well to the idea of being able to check the rules themselves through an online interface that would enable them to upload their models (as described above) and get feedback on their progress. It was not possible to fully integrate this in the case study semester, however students in a parallel course provided mockups of what such a dashboard integrated into their LMS would look like (Figure 4). This approach would require a simple interface focused on the requirements and guidance offered by the different disciplines, but organized around elements of the building.

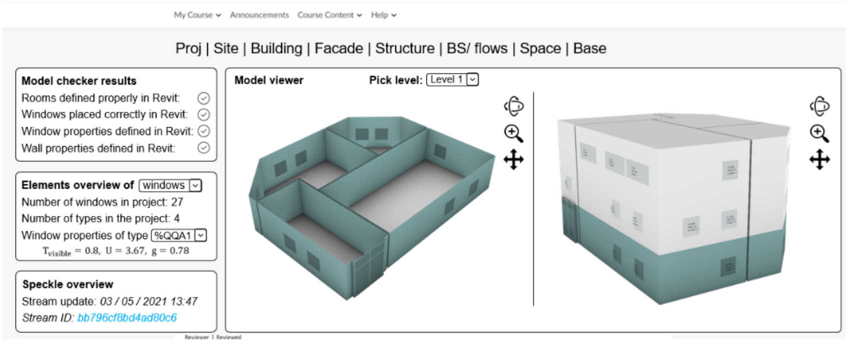
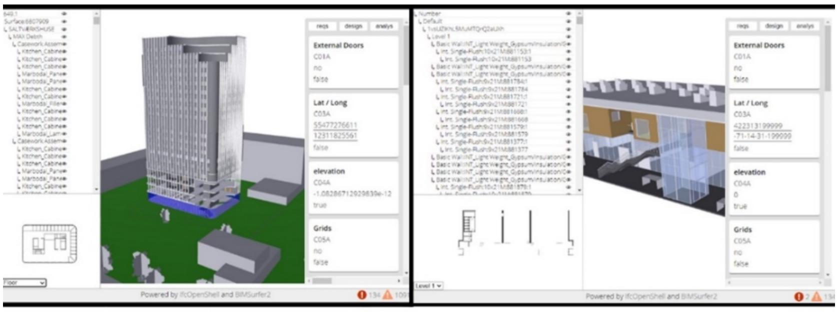


Figure 4. Student mockup of potential interface in the learning management system that we can use in future work.

The simpler system uploads the IFC files and runs some IfcOpenShell checks on it (Figure 5). The proposed system works on larger models, but is not instantaneous, so we need to reflect in future work how this integrates into the process. One option could be to process the models as a background activity and provide the user with an alert when it is ready.



Postgraduate Interface (CS3) Undergraduate Interface (CS1)

Figure 5. example interfaces for the undergraduate and postgraduate courses showing the live project example in CS3 and fixed project example in CS1

It could then use this information combined with other project and course information to build a basic 'look up table' for the building. Including building information such as the number of floors and total height of the building. The rules and tools that would be produced by CS2 could then be used to support the development of the disciplinary models in the design course. These rules would be integrated into the course Learning Management System (Figure 4) enabling real time feedback to students in CS1 and CS3 (Figure 5). In this way the rules are expanded beyond BIM quality checks to include issues such as performance against the project requirements. Based on the experience of assessment in CS2, it appears that automation of assessment of BIM models in large class teaching is possible, however it requires that effort is made to write and check the rules before the course, so that students can learn from their BIM early in the course to support them to learn *from* BIM.

5 Conclusion

Framing BIM in a learning paradigm using Succar's manifestations of abilities, activities and outputs and incorporating learning management systems (LMS) enables the user to receive realtime feedback on their progress in the project to support them to learn *from* BIM. The abilities cannot be provided in a single 'BIM' course but need to be supported as part of an integrated family (ecosystem) of courses. A future signature pedagogy of BIM could based on choices from the student: how they think (fixed or dynamic); perform their roles in the future (offer guidance) and define their own moral position on BIM tools (acting with integrity). If (some) students in CS2 contribute towards the OpenBIM tool development and this can be replicated in more universities, there is an opportunity to shift the tide in BIM towards the celebration of an Open BIM ecosystem of tools that students and professionals alike can learn from. This shift in emphasis from teaching, to learning from BIM would create an inspirational environment for the next generation of research and innovation activity, to support more OpenBIM tools in the AEC.

Acknowledgements

DTU Teaching Development Fund, 2018 (Agile Building Design Platform)

References

Beetz, J., (2019) IfcOpenShellScriptingTutorial, Github Repository, https://github.com/jakob-beetz/IfcOpenShellScriptingTutorial

Berglund, A., Lister, R., (2010) Introductory programming and the didactic triangle. In: Proceedings of the Twelfth Australasian Conference on Computing Education - Volume 103 (ACE '10). Australian Computer Society, Inc., AUS, 35–44.

BuildingSMART, 2021, Individual Qualification Scheme Launched: New framework to promote consistent training, BuildingSMART International. available at: https://www.buildingsmart.org/individual-qualification-scheme-launched/

Day, M., (2020) Autodesk AEC customers demand better value, AECMagazine, https://aecmag.com/bim/letter-to-autodesk-aec-customers-demand-better-value/

Diedrichs A., Karlshøj, J. Hertz, K. D., (2011) Multidisciplinary teaching – Engineering course in advanced building design https://findit.dtu.dk/en/catalog/157104672

Gu, N., Singh, V & London, K (2015) 'BIM Ecosystem: The Coevolution of Products, Processes, and People', Building Information Modeling, John Wiley & Sons, Inc., Hoboken, NJ, USA, pp. 197–210, http://doi.wiley.com/10.1002/9781119174752.ch15

Hansen, C. C. (2021), Automation in Construction; A Business Process Management Perspective, Master Thesis, Available at https://findit.dtu.dk/en/catalog/2644416595

Kansanen, P., (1999) Teaching as Teaching-Studying-Learning Interaction, Scandinavian Journal of Educational Research, 43:1, 81-89, DOI: 10.1080/0031383990430105

Karlshøj (2016) Open BIM in course on advanced building design - https://findit.dtu.dk/en/catalog/2350715901

McGinley, T., Vestergaard, T., Jeong, C., Pind., An OpenBIM workflow to support collaboration between Acoustic Engineers and Architects, 8th International Buildings Physics Conference 2021 (IBPC 2021) 25-27 August 2021, Lyngby, Denmark.

Messner, J., Anumba, C., Dubler, C., Goodman, S., Kasprzak, C., Kreider, R., Leicht, R., Saluja, C., and Zikic, N. (Under Development). BIM Project Execution Planning Guide, Version 3.0. Computer Integrated Construction Research Program, The Pennsylvania State University, University Park, PA, USA, Available at http://bim.psu.edu

Puolitaival, T. and Forsythe, P. (2016), "Practical challenges of BIM education", Structural Survey, Vol. 34 No. 4/5, pp. 351-366. https://doi-org.proxy.findit.dtu.dk/10.1108/SS-12-2015-0053'

Rustici (2021) XAPI, available at: https://xapi.com/

Sampaio A.Z. (2021) BIM Education Required in Construction Industry. In: Rodrigues H., Gaspar F., Fernandes P., Mateus A. (eds) Sustainability and Automation in Smart Constructions. Advances in Science, Technology & Innovation (IEREK Interdisciplinary Series for Sustainable Development). Springer, Cham. https://doi-org.proxy.findit.dtu.dk/10.1007/978-3-030-35533-3_1

Shulman, L. (2005). Signature Pedagogies in the Professions. Daedalus, 134(3), 52-59. Retrieved June 19, 2021, from http://www.jstor.org/stable/20027998

Succar, B. Sher, W. Williams, A. (2013) An integrated approach to BIM competency assessment, acquisition and application, Automation in Construction, Volume 35, Pages 174-189, ISSN 0926-5805, https://doi.org/10.1016/j.autcon.2013.05.016

Tinto V. (2017) Through the Eyes of Students. Journal of College Student Retention: Research, Theory & Practice. 2017;19(3):254-269. doi:10.1177/1521025115621917